DOMINION OF CANADA
DEPARTMENT OF AGRICULTURE
DOMINION EXPERIMENTAL FARMS

DIVISION OF BOTANY

INVESTIGATION
OF
POTATO DISEASES

By
PAUL A. MURPHY, B.A., A.R.C.Sc.I.
Assistant in charge of Plant Pathological Field Station for P.E.I.

BULLETIN No. 44.
Second Series

Published by direction of Hon. Dr. S. F. Tolmie, Minister of Agriculture, Ottawa, Ont.
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OTTAWA, February 8, 1921.

The Honourable
The Minister of Agriculture,
Ottawa.

SIR,—I have the honour to submit herewith the manuscript of Bulletin 44 on "Investigation of Potato Diseases," prepared by Mr. P. A. Murphy, lately Assistant in Charge of the Plant Pathological Field Station for Prince Edward Island.

The observations placed on record in this bulletin are the results of the investigation of a number of potato diseases of common occurrence in Canada. The work was undertaken with the object of inquiring into the relation of climate and environment as affecting the severity of the diseases, and incidentally to find out the need for and the nature of modifications relative to the successful control of said diseases.

The work was begun by the officers of the Division some years ago and was continued by Mr. P. A. Murphy, who, in the present pages, gives an account of this work while an officer of the Dominion.

The bulletin contains information that will be of use to the student and investigator, as well as the farmer who is desirous of keeping in touch with the progress of work relating to the investigation and control of plant diseases.

I have the honour to be, sir,

Your obedient servant,

E. S. ARCHIBALD,
Director, Dominion Experimental Farms.

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INVESTIGATIONS ON POTATO DISEASES

PAUL A. MURPHY

LATE BLIGHT [*Phytophthora infestans* (Mont.) De Bary].

The late blight of potatoes occurs every year in Prince Edward Island, the greater part of Nova Scotia and in considerable portions of New Brunswick and Quebec. The disease is more severe in these provinces and the resulting losses greater than possibly in any portion of North America. One of the worst features is the large amount of tuber rot which often follows an attack, either in the field or in storage. Particularly in the more easterly districts it is not uncommon to find cases in which white varieties decay during winter to the extent of 75 to nearly 100 per cent of the crop. In most years the unsprayed field which shows no loss from rot is rare.

EXTENT OF LOSSES FROM BLIGHT

Definite figures have been gathered showing the amount of rot which developed from digging time to the following April in unsprayed potatoes of a considerable number of the commoner varieties in Prince Edward Island (figures for 1919 show the rot to November only).

TABLE 1.—Amount of late blight rot in unsprayed potatoes in Prince Edward Island.

Year	Percentage by weight of unsprayed crops which rotted
1915	1·2
1916	29·5
1917	15·6
1918	27·6
1919	32·7
Average for 5 years	21·3

An approximation to the total loss from late blight, including the rot of the tubers and the reduction in yield due to the premature killing of the plants, may be obtained from the results of five years of careful spraying in which blight was held in practically perfect control on some plants and allowed to take its course on others. It is found in this work that blight reduced the marketable yield on the average during the five-year period by 130½ bushels per acre. The figures year by year from 1915 to 1919 are as follows:—

TABLE 2.—Increase in marketable potatoes due to spraying in Prince Edward Island, this being the measure of the loss from late blight.

Year	Amount of potatoes by which late blight reduced the crop (including late blight rot up to April)
	Bush. per acre
1915	100·5
1916	167·5
1917	121·0
1918	100·5
1919	163·0
Average for 5 years	130·5

Much the greater part of this loss is due to late blight. Early blight does a certain amount of harm and tip-burn a still smaller amount. In the above table and in all the sections devoted to blight and spraying nothing is generally mentioned except late blight because nothing else is of sufficient economic importance.

The potato crop in Prince Edward Island covers in round numbers 30,000 acres. The yield is about 200 bushels per acre and the total production 6 million bushels. Of these 200 bushels approximately 40 bushels per acre rot before spring. Were it not for late blight the yield per acre would be 290 bushels of sound potatoes and the total crop would reach 8·7 million bushels. The extent of the loss at 75 cents per bushel is $2,925,000. Included in this figure is the 20 per cent of the crop which rots, and it may be urged that this is not wasted, since most of it is fed. On the other hand no account is taken of the amount of potatoes which do not show decay until they

Fig. 1. Late blight showing the mildew on the lower side of a leaflet.

reach a distant market by which time they may have more than doubled in value; or of the injury which these potatoes do to the reputation of the Canadian Atlantic seaboard, making the price of potatoes there the lowest in the country. Equalizing the difference in freight rates, potatoes from the portions of the country being dealt with realize only 60 to 70 per cent of current prices on the world's markets. If this further injury be added it makes an additional loss which late blight causes in Prince Edward Island of $2,432,000, and a total loss of $5,357,000.

The loss in a great part of Nova Scotia and in portions of New Brunswick is similar but not quite so high. Less complete figures are available from which it appears that 30 per cent of the crop is destroyed annually in Nova Scotia and 25 per cent in New Brunswick. The money loss, valuing the potatoes at $1 per bushel, is $2,800,000 and $2,833,000 respectively.

EARLY ATTEMPTS AT SPRAYING

In undertaking the study of late blight control in Prince Edward Island it was found that the practical grower had already attempted to solve the problem for him-

self by growing more or less resistant varieties. Among the most popular of these were purple or blue potatoes like Calico and McIntyre, and red potatoes such as Dakota Red. A like cause drove growers in parts of Nova Scotia to specialize on a late red potato known locally as Clark's No. 1, and in other parts on Prince Albert, Calico, and Garnet Chili. In eastern New Brunswick the choice ran to varieties like Silver Dollar, possibly for the same reason.

Spraying for potato blight was introduced at a later date and various attempts were subsequently made to popularize white varieties. So far as Nova Scotia and Prince Edward Island are concerned neither course was a success. Cases are known in which not enough of the white potatoes withstood the rot to provide seed for the following year, and it is doubtful if there was a single grower, of the few that kept it up, who was making a commercial success of spraying five years ago. The experience of one grower who sprayed as well as he knew how and yet lost three-fifths of his crop from rot was probably not infrequent. Our work seems to show that the principal causes of the failure were poor equipment, application of too small quantities of spray, and failure to keep up the work in the latter part of the season.

WHEN TO SPRAY

It has been found that four thorough applications of spray at intervals of about two weeks generally control blight satisfactorily. Five or six applications frequently give better returns, so that four are to be looked on as the minimum. An experiment of four years' duration was carried out to determine the best time to begin the work. This was found to be July 21 in 1916, August 4 in 1917, July 16 in 1918, and July 22 in 1919. The number of applications which gave the best results in these years appears from table 3.

TABLE 3.—Best spraying schedule for Prince Edward Island.

Year	Date of first spray	Date of last spray	Approximate interval between sprays	Total No. of sprays
1916	July 21	Sept. 29	2 weeks	6
1917	Aug. 4	Sept. 29	2 weeks	5
1918	July 16	Sept. 25	2 weeks	6
1919	July 22	Sept. 2	2 weeks	4

If it is decided to make no more than four applications the best dates to put them on will be found in table 4. This table also shows a comparison of the use of four applications with five or six.

TABLE 4.—Best schedule for four applications of spray in Prince Edward Island.

Year	Four sprays			More than four sprays	
	Date of first spray	Date of last spray	Increase in yield	No. of sprays	Increase in yield
			Bush. per acre		Bush. per acre
1916	Aug. 18	Sept. 29	140	6	162½
1917	Aug. 4	Sept. 15	99	5	108⅓
1918	July 30	Sept. 10	53	6	100
1919	July 22	Sept. 2	325	5	163 [1]

[1]The soil was not as uniform in 1919 as might be wished and this may account for the comparatively low figure here.

Where spraying was carried out four or more times (table 3) the average date of commencing was July 24 and the date of ending was September 21. Where the work was done four times only (table 4) the corresponding dates were August 3 and September 14. The importance of the late applications is to be emphasized whichever plan is followed. This is clearly seen in the tables in the years 1916, 1917, and 1918. The results in 1919 were abnormal and it may be questioned if the figures here recorded for that year fairly represent the facts. If spraying is to be economized it is better to do it in the early part of the season than in the later. When one has to spray early owing to insect attacks the necessity for the late applications is in no way diminished.

TABLE 5.—Best schedule for four applications of spray in New Brunswick and Nova Scotia.

Place	Four sprays				More than four sprays	
	Year	Date of first spray	Date of last spray	Increase in yield	No. of sprays	Increase in yield
				Bush. per acre		Bush. per acre
Nappan, N.S.	1918	July 21	Sept. 1	25½	5	27½
	1919	Aug. 4	Sept. 15	114	5	102
Fredericton, N.B.	1918	July 17	Aug. 28	82	5	81½
	1919	...	...	86	7	106

The foregoing remarks have particular reference to Prince Edward Island and eastern Nova Scotia, where the season is late. The best schedule for four applications of spray in New Brunswick and the earlier parts of Nova Scotia will be found in table 5. Early spraying is of importance here, it being generally found that four applications at fortnightly intervals, beginning about the middle of July, effect good commercial control in most years. It will, however, be profitable to spray oftener in wet seasons, and this course may be necessary to control rot in some districts.

A good practical time table for those who intend to spray four times might therefore be suggested as follows:—

TABLE 6.—Spraying schedule for the Maritime Provinces.

——	Late districts P.E.I., etc.	Earlier districts N.S., N.B., etc.	Stage of growth
First spray	First of August	Middle of July	When the flower buds first appear.
Second spray	Middle of August	First of August	2 weeks later.
Third spray	End of August	Middle of August	2 weeks later.
Fourth spray	Middle of September	End of August	2 weeks later.

If more than four applications are to be made the first may be moved perhaps a few days forward, the remainder made to follow at fortnightly intervals (or closer if the weather is wet), and the last to come one to two weeks later than in the time table above. The safest way to judge the time to begin is to watch the little stalks bearing the buds of the future blossom. Spraying may be begun in a normal year

when they appear. If the weather in July is wet the date may be advanced, while in dry seasons no harm is done by waiting. In the abnormally wet July of 1918 the best results were obtained by beginning as early as July 16 in Prince Edward Island (table 3).

BEST TYPE OF SPRAYER

The best blight control is secured by the careful use of a knapsack or bucket hand-sprayer but neither is of use except on small plots. A cart sprayer driven by hand or horse-power has to be used in practically all commercial undertakings. These machines vary greatly in efficiency, and the selection of the best type makes all the difference between success and failure.

We have used three makes of horse-sprayers with one, two and three-cylinder pumps, running one, two and three nozzles to the row; also several kinds of hand-driven machines with varying numbers and arrangements of the nozzles. Four of these machines were used in a test on a field scale in 1917 at the Experimental Station, Charlottetown, P.E.I., through the courtesy of the superintendent, details of which are given in table 7. It appears very clearly that the larger the machine, the more spray applied per acre, and the higher the pressure (no data are given on this point but it is important), the better will be the results and the higher the net profit, notwithstanding the higher cost of the heavier applications. The best type of hand-pump and one-cylinder horse-power machines are about on a par, and their efficiency, as ordinarily used, is not more than one-half of the high-pressure sprayers. In demonstration work in 1918 with outfits of these two types it was found that a three-cylinder horse-power sprayer increased the yield by 77½ bushels per acre on the average, while the average increase for one of the most efficient hand-pumps we know of was, under the same conditions, 40 bushels per acre.

TABLE 7.—Comparison of various types of sprayers.

No. of sprayer	Power	No. of cylinders to pump	No. of nozzles per row	No. of gallons applied per acre	Cost of spraying one acre four times	Increase in marketable potatoes over checks	Net profit per acre from spraying
					$	Bush. per acre	$
1	Horse	2	3	80	6·60	63½	41 02
2	Horse	1	1	35	3·28	35½	23 34
3	Hand	1	2	40	4·04	40½	26 33
4	Hand	1	1	26	2 82	7½	2 80

(Potatoes valued at 75c. per bushel.)

Potato growers would be well advised not to be too economical in the purchase of a spraying machine. There are good and bad makes on the market, but the best choice will be made by attending to the important points, which are high pressure, rigid construction and absence of unnecessary complications. A pressure of 125 pounds with all nozzles working is essential, and to obtain this a two-cylinder, or preferably a three-cylinder pump is required. The best number of nozzles to the row is two or three, four rows being sprayed at the same time. The arrangement of the nozzles is not important when high pressure is maintained. The ideal sprayer is the one which embodies these points and as little else as possible.

Machines of this type now (1919) cost over $200 and are therefore somewhat expensive for the average grower. Excellent results have, however, been secured by groups of two to five or even more growers co-operating in the purchase of one outfit in both Prince Edward Island and Nova Scotia. Thirteen sprayers were bought in this way in 1917 and the results were so satisfactory where the best types were

purchased to begin with that the number was added to in 1918 and again in 1919. In one district in which a lower grade machine was extensively tried on this plan the results were disappointing and spraying was again discontinued because the machines were useless after two years' work. To offset this the result in another locality may be given. Two of the largest sprayers on the market were bought in 1917 and used by about fifteen growers on fifty acres of potatoes. The owners estimated that their crops were about twice as large as those of their neighbours which had not been sprayed, and all the sprayed potatoes were sound. Some of these men had lost three-fifths of their crop in the preceding year from rot. It has been estimated that good spraying produced an extra yield of 8,250 bushels on these farms in that year, which being valued at 75 cents per bushel, and the cost of spraying one acre four times estimated at $6.60, leaves a net profit of $5,857.50. One of the growers said that if he never saw the sprayer again after one year's use it would owe him nothing. Two more machines of a similar type were purchased in the same district in 1918, and again two in 1919, making six in all.

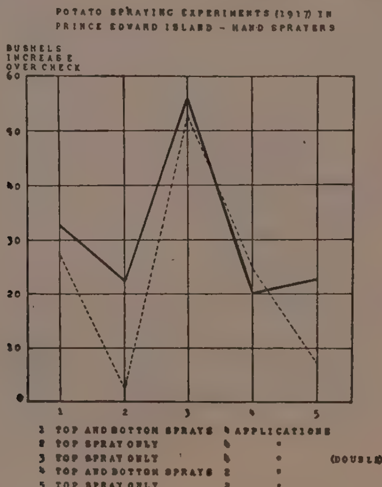

Fig. 2—Duplicate experiment with hand-power sprayers.

This experience was more or less duplicated in every locality where a proper start was made. These are unfortunately comparatively very few, when it is remembered that there is the same loss from blight and the same need for spraying in almost every settlement in the greater part of the Maritime Provinces.

BEST WAY TO USE HAND SPRAYERS

It is frequently impossible to interest sufficient people in a district to purchase a large sprayer, and hand-power machines have to be used. Several experiments have been undertaken to determine the best types of these machines and the best way to use them.

While the small pumps generally sold by small dealers and mail-order houses are nearly useless, good success was had with large hand-pumps when the field was sprayed twice over in opposite directions at the time of each application (fig. 2).

The chart shows the result of two experiments carried out in 1917 in different parts of Prince Edward Island. The increased yield is shown in one case as a continuous line and in the other as a dotted line. The superiority in both experi-

ments of the third plot, which had four double applications put on from the top only, is clear. Incidentally it may be remarked that four nozzles are enough for any hand-pump. The reason why the plots which had the top and bottom sprays in these experiments are so comparatively poor is that there was not pressure enough to supply the extra nozzles effectively.

In spite of this very successful result the use of hand-sprayers is not recommended if any other course is open. While good returns may be obtained, their use calls for more time, labour and care than the average farmer is able to devote to the operation.

THE COST OF SPRAYING

Detailed figures were obtained as to the cost of using various sprayers in connection with the trials carried out at Charlottetown in 1917. It appears from table 8 that the charge per acre per spraying varies from 70½ cents to $1.65. Comparing these figures with the net profit from the operation shown in table 7, it is evident that the expenditure of the larger sum is justified, the net return per acre being $41.02, while the net return from the cheapest spraying is only $2.80.

TABLE 8.—Record of cost of spraying with various machines

No. of Sprayer	1	2	3	4
Power	Horse	Horse	Hand	Hand
Number of cylinders in pump	2	1	1	1
Number of nozzles per row	3	1	2	1
Capacity of tank in gallons	80	40	40	40
Number of gallons applied per acre	80	35	40	26
Time in minutes required to fill tank	15	8	8	8
Time in minutes required to drive to field and back	10	10	10	10
Time in minutes required to empty tank	20	23	20	31
Total time in minutes to fill and empty tank	45	41	38	49
Number of acres sprayed in day of 10 hours	13	16½	15	18¾
Charge for horse for 1 day	$ 2 00	$ 2 00	$ 2 00	$ 2 00
Charge for man (or men) for 1 day	1 50	1 50	3 00	3 00
Total	3 50	3 50	5 00	5 00
Charge for horse and man (or men) to spray 1 acre once	0 27	0 21	0 33	0 26½
Materials for spraying 1 acre once:—				
Copper sulphate at 15c. per lb	$1 20	$0 52½	$0 60	$0 39
Lime at 1c. per lb	0 08	0 03½	0 04	0 02½
Total charge for materials to spray 1 acre once	1 28	0 56	0 64	0 41½
Interest on investment at 6 per cent	$9 00	$4 20	$1 80	$1 62
Depreciation (One fifth of value)	30 00	14 00	6 00	5 40
Total	39 00	18 20	7 80	7 02
No. of acres assumed to be sprayed in life of machine	400	400	200	200
Interest and depreciation to be charged to spraying of 1 acre once	$0 10	$0 05	$0 04	$0 03½
Charge for labour for spraying 1 acre once	$0 27	$0 21	$0 33	$0 26½
Charge for materials for spraying 1 acre once	1 28	0 56	0 64	0 41½
Charge for interest for spraying 1 acre once	0 10	0 05	0 04	0 03½
Total cost of spraying 1 acre once	$1 65	$0 82	$1 01	$0 71½

SPRAYING MATERIALS TO USE

Nothing has been found so far to equal home-made Bordeaux mixture as a spray. Varying strengths have been tried without finding that much difference resulted. The 2:2:40 formula (2 pounds copper sulphate or bluestone, 2 pounds quicklime, and 40 gallons water) gave as high yields as the 4:4:40 mixture, but there was a little more rot where the former was used. Increasing the amount of copper suphate so as to

make the strength equivalent to 6:4:40 or 8:4:40 did not materially increase the yield. On the whole the standard 4:4:40 mixture is to be recommended as efficient under all conditions and not wasteful of copper sulphate. Some growers think it useful to increase the strength for the last applications to 6:4:40 or 8:4:40 because rot is said to be reduced thereby. We have not been able to establish this feature.

Burgundy mixture (sometimes called "Soda Bordeaux") is compounded with washing soda (sodium carbonate) in place of lime. It is popular in certain countries because of the scarcity of lime, and of the absence of sediment and consequent danger of the nozzles clogging. It is also believed to have greater efficiency. The drawback to its use is that it requires more care in preparation so as to have just enough soda to neutralize the copper sulphate and no more. The strength generally recommended is 4:5:40, that is 4 pounds copper sulphate and 5 pounds washing soda to 40 gallons of water. The mixture has never been popular in Canada or the United States. Among other strengths 4:5:40 Burgundy was tested against 4:4:40 Bordeaux in 1916 and 1917. The results (table 9) show that Bordeaux was much the better the first year, while there was no appreciable difference in the second. Early blight was severe in 1916, particularly so on the Burgundy plots, while it was little in evidence in 1917, and failure to control it was the probable cause of the poor showing of the soda mixture in the former year. In Ireland, where Burgundy mixture is very popular, early blight is of no account.

TABLE 9.—Comparison of Bordeaux and Burgundy (soda) mixtures

—	Yield per acre in bushels	
	1916	1917
Bordeaux 4 : 4 : 40	276	248
Burgundy 4 : 5 : 40	197	246
Difference in favour of Bordeaux	79	2

Factory-made Bordeaux pastes are frequently sold to farmers as being easier to use and just as efficient as home-made sprays. One of these preparations sold under the name of "Kil-tone" was tried in 1915, with comparatively unsatisfactory results. The paste controlled blight and rot to considerable extent, but not so well as home-made Bordeaux. Its cost was also considerably higher, about 50 per cent more per pound than copper sulphate. Against this has to be set the advantage of being slightly easier to prepare.

TABLE 10.—Comparison of home-made Bordeaux mixture and a prepared Bordeaux paste

—	Home-made Bordeaux	Factory-made Bordeaux
Average increase in marketable potatoes over unsprayed plots. Bush. per acre	109	92
Average superiority of home-made to factory-made Bordeaux. Bush. per acre	17	
Cost of materials per acre for 4 sprays	$ 9 12	$10 88
Average net profit per acre over unsprayed plots	45 38	35 12
Average increase in net profit from spraying with home-made over factory-made Bordeaux	10 26	
Percentage of total crop which rotted (to December)	0·6	9·6

It must be noted in passing that lime-sulphur, so commonly used on fruit trees, is worse than useless on potatoes. Tried at Kentville in 1917 it reduced the yield of marketable potatoes three bushels per acre below that of the unsprayed plots.

INFLUENCE OF THE WEATHER ON THE TIME TO SPRAY

An experiment was carried on for two years at Charlottetown to find out if it is necessary to pay strict attention to the weather in spraying potatoes, as for instance in spraying apple trees, to get the spray on before a rainy period so as to obtain the best results. Two plots were treated alike except that one was sprayed as nearly as possible before periods of rain while the other was sprayed after rain. Neither plot was sprayed when the foliage was wet and the spray was not washed off in any case. A third plot was left unsprayed. The results are shown in table 11.

TABLE 11.—Effect of spraying potatoes before and after rain.

Year	Variety	Total yield of sound potatoes per acre			Increase over check		Difference in favour of spraying before rain
		Sprayed before rain	Sprayed after rain	Unsprayed	Sprayed before rain	Sprayed after rain	
		Bush.	Bush.	Bush.	Bush.	Bush.	Bush.
1916	Cumming's Pride.......... .	487½	440½	358	129½	82½	47
1917	Green Mountain............	263	228	167	96	61	35
	Cumming's Pride............	429	367	226	203	141	62
	Garnet Chili..............	295	267	216	79	51	28
	Pat's Choice.............. .	368	395	205	163	190	−27
	McIntyre...	272	261	201	71	60	11
	Average............. ...	....	....	....	123½	97½	26

It will be seen from the last column that in every case but one there was a distinct advantage in getting the spray on before rain, the difference amounting on the average to 26 bushels per acre. Were the single experiment excluded in which spraying after rain gave the better results (this being evidently exceptional), the average difference in favour of spraying before rain would be 36½ bushels per acre.

This is a matter of some importance since many growers are afraid to spray when rain threatens for fear of the mixture being washed off. The advantage of so doing is surprisingly great, although it is, of course, during wet weather that the plants need protection, beceause it is then infection occurs. It may be thought that a spray put on after one rain might be just as well said to be before the next, since rains are so frequent in many parts of the Maritime Provinces. This is not entirely so, as the experiment shows. From 20 to 30 per cent better returns will be secured if applications are made before and not after rain. The spray will not be washed off as long as it has had a chance to dry.

THE PRINCIPAL CAUSE OF ROT IN THE MARITIME PROVINCES

Nearly all the rotting of potatoes in the Maritime Provinces, particularly in the autumn, is due in the first place to the late blight, that is, of course, apart from freezing injury in the field, in storage or in transit. The blight rot itself is able to destroy the tuber, but quite frequently it is followed by other agents which hasten the process. When late blight rot is present without complications the potato remains firm and dry; there are brown or livid blotches under the skin, which may be somewhat pitted or pock-marked; and the flesh, particularly near the outside, is flecked with rusty brown spots. This is the typical "dry-rot"—the name generally given it by eastern potato growers. (Figure 3).

A soft rot frequently follows the dry stage either in the field or in storage, particularly in wet seasons and on wet land. The potatoes become wet and soft, the soft rot being at first confined to the margin, unlike the soft rot following black-leg which begins at the stem-end and attacks the heart of the potato (figure 8). The whole tuber ultimately becomes reduced to slime. It is frequently difficult to recognize

the presence of late blight in such potatoes from an external examination, but if they are cut the characteristic brown marks in the flesh may be found if they are present. If they are, it may be confidently assumed that the blight was the original cause of the trouble and that the bacteria which produce the soft rot have only been following in its wake. Although the soft rot finally gets the upper hand it is in most circumstances harmless unless the way is opened for it by some other injury.

Another fungus is sometimes put down as the prime cause of rot although it generally follows injuries due to other causes. This is the *Fusarium* dry rot. Affected portions of potatoes become hard and shrunken and the skin over them wrinkles up in a characteristic way (fig. 4). If the tuber is cut, hollows will be found inside which may be filled with white or coloured moulds, and the same moulds often

Outside view.

Inside view.

Fig. 3. Late blight rot of the tuber. This is the form the rot takes when there are no complications.

appear on the wrinkled surface. The parasite which causes this rot is generally dependent on a previous wound or injury for gaining an entrance into the tuber. Sometimes this is a cut or bruise, more rarely it is a frost-injury, and in many cases it is a spot of the late blight rot. This point may be verified very frequently by looking for the brown blight flecks in the flesh of tubers showing the wrinkled *Fusarium* rot. In later stages the latter takes complete possession of the potato, and no trace of anything else can be found.

The conclusion that late blight is the preponderating cause of rot in the Maritime Provinces is based on laboratory tests and field observations. It is also supported by the result of spraying experiments. There are farms on Prince Edward Island on which white potatoes have been largely lost for five successive years from a soft rot. Where the potatoes were sprayed so as to control blight this rot has been absent, the reason being that it followed late blight although the blight was not always obvious on ordinary inspection. In the same way *Fusarium* dry rot, particularly in the fall, is best controlled by preventing blight.

Some growers are inclined to be misinformed on these points. One hears sometimes that there is a particular form of wet or dry rot on individual farms which is different in nature and does not respond to spraying. No grounds have been found

for these assertions. It is not too much to say that if late blight were controlled there would be little rot worth speaking of (apart from frost injury) in the Maritime Provinces. This is also the conclusion of Morse (40) in Maine.

FACTORS WHICH INFLUENCE LATE BLIGHT ROT—OBSERVATIONS IN 1917.

There are certain seasons in which late blight is severe on the foliage while causing little or no rot in the crop. Nineteen hundred and fifteen was such a year. In other years the blight is much less in evidence but a large proportion of the tubers may be destroyed. Even in the same season and in the same field it is difficult to judge from

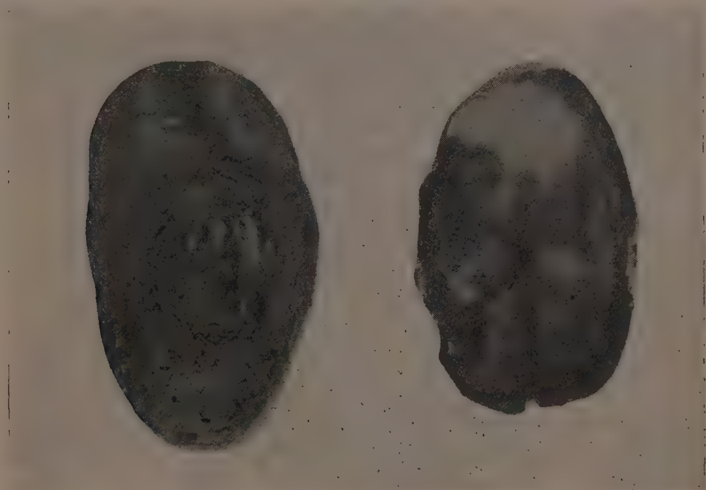

Fig. 4. Late blight followed by *Fusarium* dry rot.

the appearance of the foliage in the latter part of the season which of a number of plots will show the most rot. There is no reason to suppose that the tuber infection comes from any other source but the leaves, since foliage entirely free from blight produces a crop free from late blight rot. It must therefore be concluded that the conditions under which potatoes are grown have a considerable influence in determining if the infection will reach the tubers, and if so, in what quantity.

Practical growers have been more or less aware of this. It is, for instance, common knowledge that rot is more prevalent on wet soils than on dry. Manure, particularly when applied heavily in the spring, is generally held to promote rot. New land is generally favoured as against old. These things, although they may not be all unreservedly true, show that the influence of external conditions has been considered.

An important observation was made in 1915 which has been found to have general application. When the blight is severe enough early in the season to kill off the foliage several weeks before digging-time the crop is likely to be comparatively sound. When, on the other hand, the blight comes later and hangs on until the end of the season, rot is apt to be general. Thus it was found that less rot followed the most severe blight attack in five years, which occurred in 1915 and killed all the foliage early in September, than resulted from the less severe outbreaks of the following years (cf. table 1).

An opportunity came to test this point further in 1917. The two last applications of spray had to be omitted on a field of one acre of potatoes which was divided into twelve plots and was being used for a spraying experiment. Three of the plots had then been sprayed four times, three plots three times, two plots twice, one plot once,

and three plots had no spray. The last application was made on September 3, and after that, blight was allowed to develop. Digging was begun early (October 3) when the foliage of all the plots but the checks was still partly green and partly blighted. The unsprayed plots had been dead for some time. There had been no frost. A fair increase in yield over the checks was found in most plots, and there was somewhat more rot in the latter than in the sprayed potatoes, with one exception (table 12, column 3). The crops were then sorted, graded and put in the cellar, where they were again picked over in November and in spring. As will be seen from columns 4 and 5 of the same table only 4.3 per cent of the unsprayed potatoes rotted in storage, while the average amount of rot in those which were sprayed was 15.3. Even with the field rot added, this being highest in the checks, the percentage of rot in the unsprayed plots came to 11.0 per cent, while it reached 18.5 per cent on the average in the sprayed plots. On the whole the plots which were sprayed oftenest had the greatest total of rot, those sprayed less often had less, and the unsprayed plots had considerably the least.

TABLE 12—DEVELOPMENT OF ROT IN PARTIALLY SPRAYED AND UNSPRAYED POTATOES.

Plot	Numbers of the sprays applied	Percentage of the crop affected with late blight rot				Average net weight of sound potatoes
		In the field	In the cellar to Nov. 30	In the cellar to foll. April	Total	lb
1	1 2 3 4	1·6	13·0	0·4	15·0	
2	2 3 4	1·9	23·0	2·4	27·3	
3	Unsprayed	7·2	4·8	0·0	12·0	
4	3 4	3·3	12·0	0·3	15·6	
5	4	6·0	10·5	0·0	16·5	
6	Unsprayed	3·2	3·3	0·3	6·8	
7	1 2 3 4	1·0	10·8	2·9	14·7	
8	1 2 3 4	2·1	21·2	0·0	23·3	
9	Unsprayed	9·6	4·6	0·0	14·2	
10	1 2 3	3·7	11·7	0·7	16·1	
11	2 3 4	3·7	17·0	3·0	23·7	
12	3 4	5·7	8·7	0·0	14·4	
Average sprayed plots		3·2	14·2	1·1	18·5	386
Average unsprayed plots		6·7	4·2	0·1	11·0	363

A practically identical result was obtained from another acre plot which was let go in that year without the usual two last applications of spray. It was divided into eight plots which had been sprayed in various ways four times early in the season, and four plots which had no spray. There was somewhat more rot in the latter in the field but much less after the crops were stored. The latest figures available give the rot up to November 30, when the unsprayed potatoes showed 12·7 per cent of rot while the partially sprayed plots had 27.7 per cent.

It thus appeared that a method had been devised for obtaining a crop which would rot, namely by regulating blight by partial spraying so that the foliage although blighted, would remain living until digging-time. It was argued that there were two probable explanations of this result, either—

(1) The leaves being kept in a blighted but partly living condition for a long time, there was a supply of conidia at hand to be washed down to the tubers by every rain, thus increasing the chance of infection; or

(2) When the blighted foliage remained alive until digging-time the surface soil was kept infected by the continual dropping of conidia. This contaminated soil and the foliage itself infected the potatoes when the latter were brought into contact with them in the operation of digging.

PREVIOUS WORK ON THE SOURCE OF ROT INFECTION.

It was found in an attempt to answer these questions that similar or related problems had been met by others. Numerous references occur in the literature of the subject to the difficulty of correlating attacks of rot in the tubers with the amount of blight on the foliage. A partial reason for this may be a difference in resistance between the leaves and the tubers, as Stuart (68) has shown. Since de Bary (12) proved that tubers contracted the disease through the agency of conidia washed down from the leaves, the most important addition to our knowledge has been the work of Jensen (24). This author showed that the deeper the potatoes were covered with soil the less rot developed, due to the spores being held among the soil particles as in a filter, and he elaborated a method of making the rows so high that the potatoes were covered to a depth of 7 to 12 cm. (approximately 2½ to 5 inches). The bending of the stalks to one side so that the foliage was over the furrow was also advocated. A third precaution which he employed was to leave the crop in the ground until two weeks after the stalks were dead so as to reduce infection from contact of the tubers with partially blighted foliage. These very original and practical suggestions never seem to have become widely practised although later work has proved their soundness.

Attention was again directed to a serious source of tuber rot by Jones and Morse (27). This work is summarized in an excellent paper by Jones, Giddings and Lutman (26), which may be referred to for a summary of the potato blight question up to 1912. It was found that digging the crop very early, while the foliage was partly blighted, resulted in most years in more rot developing than if the potatoes were left in the ground. It was shown experimentally that covering a heap of freshly dug potatoes with foliage on which blight was present induced rapid and thorough rot, and the inference was drawn that contact of the potatoes with the blighted leaves during the operation of digging was the cause of considerable tuber decay. This led to the formulation of a rule that where blight occurred harvesting should be delayed until a week or more after the death of the foliage, and preferably until after frost, in all but wet seasons and with crops on heavy soil. High hilling and spraying the ground were also tested and found to be beneficial in preventing tuber infection.

Clinton about the same time noticed more than once outbreaks of rot following comparatively slight but long drawnout attacks of blight, particularly late in the season. In one case this resulted in an imperfectly sprayed plot showing more than seven times the percentage of tuber rot present in an adjacent untreated plot (14). He (13) was at first inclined to attribute the blight to *Phytophthora* and the rot to other organisms (bacteria and *Fusarium*), because the tubers remained sound in some blight years but not in others. Later he connected the presence of rot with a late and protracted blight outbreak in 1904, which did comparatively little injury to the foliage, and explained its absence in the severe blight attack of July, 1902, on the grounds of the early occurrence of the disease and the rapid death of the foliage (15). In later years information was sought on the influence of manure, rotation and ridging in a ten year experiment (17 and 19). The data obtained were not definite owing to the practical absence of blight, but there was less rot in the ridged plots and the yield was not reduced.

Other authors have had similar experiences. Stewart (67) mentions sprayed potatoes rotting more in storage than unsprayed ones in 1904. Osmun (47) found severe tuber rot in 1916 before and after digging following a slight outbreak of blight, which, although it came early, was long continued. Similar occurrences have probably been noted in other places, particularly in Europe where the same difficulties are known to have been met. In Holland it is recognized according to Westerdijk (70) that if spraying is stopped too soon more tuber rot may follow than if no spraying were done. This author puts forward the hypothesis that the effect of confining spraying to the early part of the season is to postpone the maturity of the crop without protecting the foliage which is produced later. When blight develops on the latter, and spores are,

in consequence, washed down into the soil, the tubers are still in a susceptible condition because of their immaturity, and infection freely follows. It is not clear how far this conclusion is based on experimental evidence. It does not appear to be applicable to Canadian conditions, for it fails to account for the altogether disproportionate amount of rot which developed after harvesting in the experiments about to be recorded, particularly in 1919.

As long ago as 1846 it was observed that the amount of rot in the tubers was not always proportional to the intensity of the blight of the foliage. To explain this it was commonly held that the tuber rot was due to some other agent than that responsible for the injury to the foliage. Fifteen years later when de Bary ((12) conclusively proved that the leaf blight and the specific tuber rot, which is generally associated with it, were due to the same cause, the fungus *Phytophthora infestans*, the same view was held. This author lists four separate agents which were held by different schools to cause the disease in the tubers, these being: "degeneration" of the potato plant, unsuitable soil conditions, *Fusarium* and similar fungi, and, finally, the circulation in the plant of poisonous products from the blighted leaves. In spite of the work of de Bary in proving all these views erroneous, some of them, as already mentioned in connection with *Fusarium,* are still put forward at the present day in order to explain apparently anomalous outbreaks of late blight rot which do not appear to have a direct connection with the blight as it occurs on leaves. The lack of connection between the two forms of the disease is, however, only apparent, as the following experiments clearly show.

FACTORS WHICH INFLUENCE LATE BLIGHT ROT—EXPERIMENTS IN 1918

In an attempt to throw further light on the relations between foliage blight and tuber rot in 1918 two areas of potatoes were so treated that they developed blight freely, and yet remained partly living until well into October. An experiment as shown in table 13 was then carried out on them in duplicate.

TABLE 13.—Experiment to determine the factors influencing late blight rot of potatoes (1918).

Plot	Treatment	Date of Digging	Percentage of crop which rotted			Net weight sound Potatoes Average 2 plots
			To Nov., 1918	To April, 1919	Total	lb.
1	Stalks removed Sept. 19. Crop dug 5 days later	Sept. 24	35·9	2·4	38·3	43
2	Stalks removed Sept. 19. Crop dug 11 days later	Sept. 30	28·7	4·3	33·0	50
3	Tubers steeped in formalin (1:240) after digging	Sept. 30	18·0	7·4	25·4	55½
4	No treatment after digging. Crop stored at once	Sept. 30	31·6	0·0	31·6	40
5	No treatment after digging. Crop left on ground all day	Sept. 30	38·7	6·3	45·0	41
6	Crop dug after heavy rain. No treatment	Oct. 7	31·8	5·4	37·2	55
7	Crop dug after first killing frost. No treatment	Oct. 20	32·5	5·7	38·2	51
10	Rows "hilled up" Sept. 19. No further treatment	Sept. 30	47·4	4·8	52·2	41½

(The crops from plots 8 and 9 were mislaid in storage).

The object of disinfecting the potatoes from the third plot with formalin immediately after their being dug was to eliminate infection at the time of harvesting, and in this way to calculate its amount. The operation is injurious and is not recommended

in practice. The fact that there was less rot here than in any other plot showed that a considerable amount of infection was to be traced to this source. At the same time since 18 per cent of this plot developed rot up to November, and a further 7·4 per cent up to April, it must be concluded that at least 18 per cent of the tubers, and possibly 25·4 per cent, were already infected before they were taken out of the ground. If plot No. 3 be compared with the four plots which were dug the same day (Nos. 2, 4, 5 and 10) it will be found that the respective percentages of rot were 25·4 and 40·4 per cent. This means that 15·0 per cent of the crop became infected at the time of digging.

Assuming the surface soil to be a considerable source of contamination, the stalks, which were then considerably blighted, were cut off and removed from two other series of plots (Nos. 1 and 2, table 13) on September 19. The plots were dug five and eleven days later respectively. As the conidia which carry the blight from the leaves to the tubers are short-lived it was believed that the ground might be cleaned up in this way. The five-day interval was certainly not sufficient, since the total amount of rot developing was 38·3 per cent. The plot on which the eleven-day interval was allowed was somewhat better with 33·0 per cent of rot, in comparison with 42·9 per cent in the three plots (Nos. 4, 5 and 10) dug the same day. This must be interpreted to mean that in this case practically 10 per cent of the crop was saved from rotting by reducing the amount of infecting material in the surface soil.

The amount of rot developing in plot 5 (45·0 per cent) is also significant of the surface soil being an important source of contamination. The crop there was allowed to lie on the ground from morning until night, with the result noted. The crop of plot 4 was dug at the same time and picked up at once. It developed 31·6 per cent of rot, or 13·4 per cent less than plot 5. It is only natural to assume that if many of the tubers are infected at digging-time in the manner suggested, the longer they are left on the ground the greater will be the chance of contracting rot.

There seemed only a little advantage in leaving potatoes in the ground until after the first killing frost (October 20), as was done in plot 7. Although the ground was probably cleaned up thereby, the frost coming so late gave many opportunities for the spores to be washed into the soil by the October storms. At the same time there was less rot in this plot than in some of those dug earlier. The high percentage of rot showing in plot 10 is probably due to the disturbance of the soil when the rows were "hilled up." This work was done much too late in the season when there was already a great deal of blight present.

FACTORS WHICH INFLUENCE LATE BLIGHT ROT—EXPERIMENT "A" IN 1919

The results in 1918 were at best inconclusive. Blight was allowed to develop too freely on the foliage so that about 25 per cent of the crop had become infected before it was dug. Conditions for the study of tuber infection during the digging operations were better in 1919. Two distinct experiments were carried out, one in quadruplicate and the other in triplicate. The result of the first experiment (A) is given in table 14.

Late blight first appeared on these plots on September 11. There was then very little present and it remained slight for a long time and was never severe. The first trial diggings were made on the 12th. There was no rot present and none developed on repeated examination of the potatoes up to October, that being the date of the last inspection. A further trial digging from every plot was made on September 19 and 20. The crop was again free from rot and remained so up to November, after which no further records were made. It was on this day that the stalks were cut off plot 2. There were then only very isolated spots of blight on the foliage. It had been checked in the preceding week but on this day it obtained a further start. The stalks were removed from plot 1 on September 24, when blight had not progressed very much further. The results, therefore, are typical of potatoes which were well looked after and remained practically

free from blight up to the latter part of September, but on which a straggling outbreak then developed. This is sometimes the case even under good management. The amount of rot subsequently found seems to be out of all proportion to the extent of the blight, but the experiment makes the connection between the two quite clear.

TABLE 14.—EXPERIMENT TO DETERMINE THE FACTORS INFLUENCING LATE BLIGHT ROT OF POTATOES (A-1919).

Plot	Treatment	Date of digging	Percentage of crop which rotted			Net weight of sound potatoes Average 4 plots
			In field	To Nov. 1919	Total	
						lbs.
1	Stalks removed Sept. 24. Crop dug 6 days later	Sept. 30	0·0	35·4	35·4	69
2	Stalks removed Sept. 20. Crop dug 10 days later	Sept. 30	0·0	4·0	4·0	112
3	Crop dug when dry on sunny day. Stored at once	Oct. 1	0·0	40·4	40·4	76
4	Crop dug when dry on sunny day. Let lie on ground all day	Oct. 1	0·0	68·3	68·3	42
5	Crop dug when wet on sunny day. Stored at once	Oct. 4	0·0	54·4	54·4	61
6	Crop dug when wet on sunny day. Let lie on ground all day	Oct. 4	0·0	55·8	55·8	58
7	Crop dug after first killing frost. Stored at once	Oct. 21	26·7	17·1	43·8	72
8	Crop dug after first killing frost. Let lie on ground all day	Oct. 21	23·1	21·6	44·7	66
9	Ground sprayed with Bordeaux, Sept. 19, 22 and 27	Oct. 7	0·0	31·5	31·5	86
10	Rows "hilled up" Sept. 5. Ground sprayed with Bordeaux, Sept. 19, 22 and 27	Oct. 7	0·0	35·4	35·4	74
11	Rows "hilled up" Sept. 5	Oct. 8	0·0	14·9	14·9	83

The most striking fact which appears from table 14 is the total absence of rot in all the plots which were dug within the period September 30 to October 4, and the subsequent phenomenal development of rot in storage in the crops of all of them except No. 2. The origin of the infection can be clearly traced in this and the next experiment.

The result of the keeping test of the two trial diggings on September 12, and again on September 19 and 20, show that no blight rot develops when the foliage is free, or practically free, from late blight. The second of these two diggings further shows that up to September 20 no tubers could have become infected by means of spores washed down to them through the soil. The infection, therefore, must have taken place subsequent to September 20.

The question then arises, was infection conveyed to the tubers while they were still in the ground between September 20 and the date on which they were dug. This point does not find a complete answer from this experiment, but it may be mentioned that the result of the next experiment clearly shows that any material amount of rot in similarly treated potatoes cannot be traced to infection of the tubers while still in the ground under the conditions of the experiments in 1919. The reason the answer is not quite complete is because there is no means of measuring the amount of infecting material carried into the soil between September 20 and 30, because, contrary to expectation, the period which elapsed between the removal of the stalks and the digging of the crop was not sufficiently long to kill the conidia. It is quite clear that the potatoes in plot 1 were infected by spores which were produced before September 24, the date on which the foliage was removed. This plot, after it was dug on September 30, developed in its crop 35·4 per cent of rot. Infection of the tubers may have taken place in the soil without having progressed far enough to be observable at digging time.

or it may have taken place when the crop was being dug. The former alternative is, on the whole, unlikely, particularly as no infection was evident in adjacent plots when dug as late as October 8. Furthermore, if so much infection could take place in the soil in a few days when blight was not severe, how much more should have developed in the plots which were dug three weeks after the first series, during which time there was no killing frost, abundant rain and more blight than earlier in the season. The total amount of rot found in these plots is not as much as was present in some of the earlier-dug potatoes.

It may be objected that the development of rot subsequent to digging was due to the disease spreading from tuber to tuber. This could not have taken place. It is also out of the question that the potatoes in plot 1 were infected by rain-borne conidia washed into the soil from adjacent plots. Plots 1 and 2 were separated from the other plots, and, though both were equally exposed to infection, very little reached plot 2.

The most likely alternative seems, therefore, to be that the tubers in plot 1 became infected when they were being dug, through contact with contaminated top soil and foliage. The relative importance of these two sources of infection is shown by comparing plots 1 and 3, which had similar treatment at digging. The former, with no foliage, gave 35·4 per cent of rot, and the other, with the foliage still on, gave 40·4 per cent. This result would indicate that conidia may remain alive in the soil for at least six days. The great difference between plots 3 and 4, which seems to be a constant feature throughout the work, is explainable on similar grounds. In the case in which the crop was picked up at once 40·4 per cent of rot followed, but where it was allowed to lie on the ground all day the amount was 68·3 per cent.

The behaviour of the remaining plots of this experiment indicates that the other factors tested were of secondary importance. Spraying the ground three times was not a material benefit when the crop was dug early, while digging after rain increased the amount of rot somewhat. The results from high hilling are very conflicting. It is believed that unless this work is done sufficiently early to allow the soil to become compacted again, more harm than good may follow. Leaving the crop in the ground until the end of the season resulted in a smaller total of rot than was found in several of the plots which were dug early, when infecting material was abundant.

FACTORS WHICH INFLUENCE LATE BLIGHT ROT—EXPERIMENT "B" IN 1919

Experiment B in 1919 (table 15) gave practically identical results. Blight developed faster here than in the previous experiment. It was first discovered on September 12, but it probably was present before that date for a few rotted tubers were found in a trial digging on the 18th. The great bulk of the potatoes were, however. sound. This is of significance in connection with plot 5 which was dug that day also and showed no rot, but which developed 35·6 per cent in storage. On the same day the stalks were removed from plots 2 and 3 and the surface soil of the latter was sprayed with Bordeaux mixture. These two plots when dug 34 days later developed a total of 8·0 and 6·1 per cent of rot respectively. Both they and plot five retained their foliage until the same date, and there was, therefore, the same opportunity for conidia to be washed down to the tubers in the soil. The only reasonable explanation of the very different keeping qualities of the potatoes seems to be that plot 5 was dug while blight infection was comparatively abundant on the surface, while plots 2 and 3 were dug after the ground had become clean.

In the case of plot one again, it was harvested originally on the same day as the stalks were removed from Nos. 2 and 3, and as No. 5 was dug. It had, therefore, the same chance of becoming infected from conidia washed down to the tubers. The stalks were taken away after the potatoes were dug, and the latter were then put back in the soil in about the same position as before, covered up again, and left until the general digging time. Such treatment should, according to the theory, increase the rot content. The result was as anticipated, there being 14·6 per cent of the tubers decayed. Why

this figure is not nearer to that found in plot five, 35·6 per cent, is not clear. It is probable that the bruising of the tubers in being crated or barrelled, hauled to the cellar or warehouse, and dumped into bins or to the ground, favours infection. It is also likely that conditions are very conducive to decay when freshly-dug and bruised potatoes are piled together, where they "sweat," as the growers say. These potatoes did not undergo this treatment.

It is noteworthy that removing the stalks nine days before digging, as was done in plot 4, did not give nearly as sound a crop as where the longer interval elapsed. Probably the period was not sufficiently long. It is evident that at least two weeks should be allowed for safety. The result here again emphasizes the importance of infection arising from the soil in distinction to that from the foliage.

TABLE 15.—EXPERIMENT TO DETERMINE THE FACTORS INFLUENCING LATE BLIGHT ROT OF POTATOES (B-1919).

Plot	Treatment	Date of digging	Percentage of crop which rotted			Net weight of sound potatoes Average 3 plots
			In field	To Nov. 1919	Total	lbs.
1	Crop dug Sept. 18. Stalks removed. Tubers restored to soil again	Oct. 22	8·7	5·9	14·6	89
2	Stalks removed Sept. 18. Crop dug 34 days later	Oct. 22	4·7	3·3	8·0	118
3	Stalks removed Sept. 18. Ground sprayed. Crop dug 34 days later	Oct. 22	3·7	2·4	6·1	113
4	Stalks removed Sept. 18. Crop dug 9 days later	Sept. 27	(1)	21·7	21·7	104
5	Crop dug early. No treatment	Sept. 18	0·0	35·6	35·6	91
6	Crop dug after first killing frost, and stored without treatment	Oct. 22	11·9	3·9	15·8	123

(1) The separate amount of rot which appeared in the field was not recorded. It is included in the total.

As in both the preceding experiments in 1918 and 1919, the maximum amount of rot developed in the plot (No. 5) which was dug early while the foliage was still comparatively green. This fact, coupled with the moderately good showing of the late-dug plot, which is also in agreement with the other experiments, proves conclusively that greater danger to the tubers may come, not from conidia washed down into the soil, but from such as are on the surface when the crop is dug. Were it otherwise, the later the digging the greater would be the amount of rot, which, as is shown, is not generally the case.

It is, of course, understood that rot is contracted by tubers while still in the soil, in some years to a very large extent. The object of the present work is to call attention to another source of infection of a baffling nature and of proportions so unexpectedly large that it exceeded the former in the experiments under review. The amount of rot arising from subterranean infection may be found in the plots dug after frost (Melhus 34), and that arising from surface infection in those dug too early for any spores to have been washed down to the tubers. Subterranean infection caused practically one-third of the crop to rot, while surface infection rotted practically one-half of it on the average.

SUMMARY AS TO THE SOURCES OF ROT INFECTION.

The following conclusions seem to be justified as holding under the conditions of the experiments:—

1. The danger of late blight rot originating from the foliage and surface soil during digging is greater than that occurring while the potatoes are in the ground.

2. The surface soil is a more serious source of infection at harvest-time than partly blighted foliage.
3. Infection may be caused by the soil certainly nine days after the stalks are removed, and probably longer, but not thirty-four days afterwards. The exact period was not determined.
4. Rot is reduced considerably by the removal of the foliage a sufficient period (probably not less than two weeks) before harvesting.

PRACTICAL APPLICATIONS.

The results here recorded throw light on attacks of late blight rot which are not uncommon in Prince Edward Island and Nova Scotia. Sometimes, when the foliage shows a not excessive amount of blight, crops of potatoes are dug, principally white varieties but also blue sorts, which appear to be sound but which rot in storage to a greater or less extent, often almost completely. There are farms on which this has happened season after season four years out of five. Rot may develop so disastrously in storage or in transit that in bad years dealers cease buying potatoes altogether in the early autumn no matter how sound they look. Some of the worst cases are known to follow imperfect spraying, particularly when the work is not kept up long enough. It is believed that the major portion of the infection in such cases comes from contact of the tubers with contaminated top-soil and foliage during the operation of digging.

It is likely that the prevalence of late blight rot along the Atlantic seaboard is connected with the long open autumn season, during which rains are frequent and killing frost often holds off until the third week of October or even early November. A combination of weather conditions is present at that time which makes blight control very difficult. Among these may be mentioned heavy dews, wind and rain storms, wet soil and favourable temperature. It is only necessary to examine potato foliage and see the luxuriant growth of blight on the leaves after the heavy night dews of late September to understand how much at home the *Phytophthora* is. After a heavy storm, when the stalks lie battered and prostrate on the wet ground, splashed all over with (no doubt) contaminated soil, the blight spreads with amazing rapidity and no spraying will hold it entirely in check. It is probable that a frost regularly occurring at the end of September or early in October would make for sounder potatoes, first by killing the foliage, and second probably by cleaning up the ground. It is possible that the action of frost may be imitated artificially.

Thorough spraying is, of course, the foundation on which the control of the late blight rot is primarily based; there are indications, however, that other measures may prove a useful adjunct. It must be emphasized that they do not replace spraying. Where they were used the best results were obtained when blight was well controlled on the foliage. The first requisite for success, therefore, is to keep blight off the leaves as completely as possible up to near the end of September, and longer if that can be done. This requires the best kind of commercial spraying from July until at least September 15 or 20. Good blight control being granted the other measures may be tried with the hope of success.

In the first place it is not open to question that the rows are not "hilled up" or made high enough in many parts of the Maritime Provinces. It stands to reason that exposed potatoes must be in danger of rotting, as indeed generally happens in practice. Although our experiments do not allow a definite conclusion to be drawn, it has been frequently shown that the more soil is over the tubers the less rot develops. If thorough covering of the potatoes had no other use than to prevent sun-burn, field-frost and the rots which follow it, it would be worth doing. It is recommended, therefore, after the last cultivation that sufficient soil should be thrown on to the rows so as to bring them to a sharp point. This operation would be facilitated, as would also cultivation and spraying, if the rows were made wider than is usually the case in

the Maritime Provinces outside of the commercial districts of New Brunswick. Thirty inches should be the minimum width instead of the usual twenty-two or twenty-four inches, and thirty-six inches might be better.

The experiments referred to clearly bear out general observations that it is unsafe to dig potatoes when the foliage is going down with blight, because more rot is likely to follow than if the crop were left in the ground. Where blight breaks out late in the season on potatoes which were previously healthy, and where it is believed the tubers are still free from infection, there are good indications that the safest course to follow is to remove the stalks and not to dig the crop until at least two weeks later. This practice is new and it is desirable that experimentalists, and growers who have trouble from rot, should give it a trial on a small scale in conjunction with the best spraying possible. It is well known that farms differ greatly in susceptibility to late blight rot of potatoes, the reasons for which are not at all clear. In many instances nothing but reasonably good spraying is needed to preserve the crop, but there are cases in which nothing but the most careful hand work gives satisfactory results, and this is not possible on a commercial scale. The new method was worked out under conditions in which the rot is exceptionally difficult to control practically every year, and for such conditions it seems to provide a remedy that is worthy of trial.

Fig. 5. Effect of spraying for late blight. Difference in yield 141 bushels per acre.

It is possible to cut off the stalks with a mower and then rake them off the field. The latter point is important if the potatoes are to be dug soon afterwards (within two weeks), because blight flourishes on the cut foliage for a considerable time, particularly in wet weather. It is believed that a better way would be to spray the plants with a poisonous chemical in order to reduce the danger of shaking down conidia from the leaves and disturbing the soil. This would also eliminate the double operation of cutting and raking. The spraying method has not been tried but it will probably be found that the formula recommended for killing wild mustard will be effective, that is, 10 pounds of copper sulphate (bluestone) in 40 gallons of water. It has been found in the experiments the results of which are available that the foliage of potato and wild mustard react similarly to several chemicals, for instance to magnesium chloride, nitrate of soda and potassium chloride (muriate of potash), 15 per cent solutions (60 pounds in 40 gallons) of all of which are fatal to both, but not

to a number of other farm crops. It is probable that a little ingenuity would discover better chemicals than these, among which might be suggested bleaching powder or soluble arsenic compounds like sodium arsenite which are used as commercial weed-killers.

The reduction in yield following the removal of the foliage on September 18 to 20 in comparison with allowing it to remain until October 20 to 22 was ten per cent of the crop in both years, or approximately 20 bushels per acre. The loss would be reduced by letting the stalks stand a little while longer, particularly if the leaves were kept in good functional condition by thorough spraying. If this could be kept up until October 1 the loss would probably not exceed 5 per cent. Even when cut off at the earlier date the loss under the conditions of the experiments was generally more than made good (tables 13, 14 and 15). The net weight of sound potatoes in November, 1919, from the plots where the stalks were cut off was 13 per cent more than from the plots in which they were allowed to grow until the end of the season. Even if there were a slight loss it would still be worth while to the grower on account of the saving of labour of extra sorting, and the benefit to the grower, shipper and community in general from the reduction of rot in transit would be of such magnitude as to be difficult to estimate.

BLACK LEG (*Bacillus atrosepticus* van Hall.)

The black leg disease of potatoes has been recorded from many countries and probably has a world-wide distribution wherever conditions are favourable for its development. It is generally distributed throughout Canada and the United States and is probably indigenous or as long naturalized as the potato itself. The contention of Morse (38 and 40) that it is a recent introduction to the United States from England, by way of Canada, is not based on evidence or in accordance with the probabilities. After attention was directed to the disease by Appel's (6) principal paper on the subject it was found generally distributed wherever it was looked for from Maine to Texas and from Long Island to Oregon.

The disease is sometimes very destructive in the Maritime Provinces, but the attack varies greatly from year to year. There was a general outbreak in 1915 in which in several cases up to 50 per cent of the plants were affected, there being, besides, an unusual number of misses, due in all probability to the same disease. In one field 88 per cent of the plants either failed to appear or were killed by black leg soon after coming up, and a small garden patch on the same farm showed an even higher amount. The average loss for that year has been calculated to be 7 per cent of the crop in New Brunswick and 10 per cent in Nova Scotia and Prince Edward Island. Valuing the potatoes at 75 cents per bushel, the total loss from the three provinces would amount to $1,627,000. Harrison (23), who published the first original account of the disease in America, records still greater losses in Ontario. There has been no such general outbreak in the Maritime Provinces in the succeeding four years, but isolated cases are met with almost every year, some of them so severe as to involve 10 to 50 per cent of the crop.

SYMPTOMS

The appearance presented by the disease is well known. Affected plants are prominent in the fields in July before any other disease occurs, although they may also occur later. They are smaller than normal as a rule. The branches and leaves have a stiff upright habit of growth instead of spreading out and drooping. The leaflets tend to roll up along the midrib, and the foliage is light-coloured or yellow instead of the normal green. Suspicious plants may be tested by pulling them up, for they leave the ground easily if they are diseased. Affected stems show a black rot which starts from the set and destroys the tissues up to the ground level or above it. In late attacks,

where tubers have been set, the rot may travel out along the rhizome and invade the tuber (fig 7), reducing it to a soft whitish pulp. In the greater part of Eastern Canada no storage rot can be traced to black leg. Either the tubers rot completely in the field, which is the usual course, or if the rot at the stem-end is only incipient, it seems to dry out after harvesting and does not spread any further during the winter

Fig. 6. Plant attacked by blackleg. One stalk already dead and the other dying.

Reports from northern Ontario, however, indicate that a serious tuber-rot may follow an attack of the disease after the potatoes are stored. The statement of Coon's (20), that "it (*black leg*) is the cause of serious rotting of tubers in storage" in Michigan, is confirmatory. The Upper Michigan peninsula, where the disease is said to be widespread, is continuous with one of the most important potato districts of northern Ontario around Sault Ste. Marie. Harrison (23) and Jones (25) have also separately described a bacterial tuber-rot of large proportions in southern Ontario, but its connection with black leg is not definitely known.

The cause of the disease is a bacterium which has been described under different names in several countries. It appears from the work of Morse (40) that the correct name for the organism occurring in America is *Bacillus atrosepticus* van Hall.

INFLUENCE OF THE SOIL AND TIME OF PLANTING

Many observations have been made tending to show that a high moisture content of the soil is necessary before the disease assumes large proportions. More diseased plants are found in low-lying parts of the field than in higher. One example out of many will suffice to show this. Observations were made in 1915 in a field near Kensington, P.E.I., in which the number of plants affected with black leg varied from 33 to 50 per cent. The rows ran up and down the face of a gentle slope, and it was noticeable that the ground at the foot of the hill was wetter than further up. The composition of the soil all over the field appeared to be uniform. It was found in extensive counts that there were three black leg plants in the low-lying area to one in the higher.

It is also a frequent occurrence to find an outbreak of black leg in early planted potatoes, but little or none at all in similar potatoes planted later. The garden, where a patch is put in for early use, often shows the disease when there is none in the field. Pethybridge (51) gives a striking illustration of the effect of planting on different dates in Ireland. Sets to the number of 120 were planted from the same stock of seed potatoes in the middle of the months of March, April, May, and June, when the following numbers of plants became diseased in each plot: March, 45; April, 24; May, 8; June 4. This probably indicates that the greater amount of moisture and lower temperature common in the early part of the season are necessary for the development of *Bacillus atrosepticus*. The cold, wet character of the season in which outbreaks occur substantiates this view. On the other hand the comparative absence of black leg in seasons presumably favourable to it is attributable apparently either to scarcity of the causal organism on the seed potatoes due to rare occurrence of diseased plants the previous year, or to other conditions prerequisite for an attack, of which we lack the knowledge. More than one season has been seen in which an outbreak was expected but did not materialize except in occasional cases.

SOURCE OF INFECTION

An experiment carried out in 1915 substantiates the view that the disease does not spread in the field and does not attack a plant unless the set was already infected. Ninety-nine healthy tubers were disinfected in formalin (1 pint in 30 gallons of water) for 2½ hours and were then cut through the stem-end into sets of equal size. All

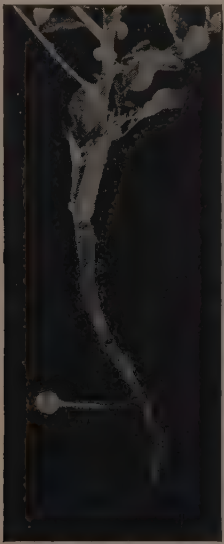

Fig. 7. Black-leg in stalk and stolon.

the tubers and sets were numbered consecutively. One-half of each tuber was planted in the room made by pulling out a black leg plant. Approximately 50 per cent of the crop in which the planting was done was going down with the disease, so that the soil should have been infected. The corresponding halves of the tubers were planted in an isolated spot which had not been broken for many years. No black leg developed in any of the plants here, nor in any of the infected field.

The presumption is that black leg is carried only by the tubers because all available evidence shows that the infection does not spread in the soil to any appreciable extent,

if at all, and does not in any case survive the winter even in the mild climates of Ireland (49) or Virginia (59). Experience and observation are unanimous on the first point here and elsewhere. While Pethybridge (50) records slight success in obtaining diseased plants from healthy tubers planted in soil artificially inoculated (presumably in spring), soil contaminated with a large amount of blackleg-rotted tubers in the autumn, when planted with clean potatoes gave a healthy crop. The same author states: "The disease, from a practical point of view, must be looked upon as one which is, in the main, transmitted by tainted seed tubers" (50, p. 14). Morse (40) as a result of ten years of experience in Maine states that "infected seed potatoes are the sole source of infection and distribution and that the disease does not live over the winter in the soil." Rosenbaum and Ramsey showed by experiments that soil contaminated in the fall with potatoes rotted by blackleg produced a healthy crop when planted with clean seed tubers the following year. The result was the same whether the work was done in northern Maine or Virginia. Ramsey (58) proved that the keeping of artificially inoculated potatoes at about 0° C. for eleven days resulted in a minimum of bacterial growth. The same author also failed to recover *Bacillus atrosepticus* from soil samples to which it had been added, and which were kept during the winter buried out-of-doors or in a cool cellar Practical failure also followed an attempt to infect pot plants by watering them with cultures of the parasite.

These experimental results are borne out by general observation. As Pethybridge

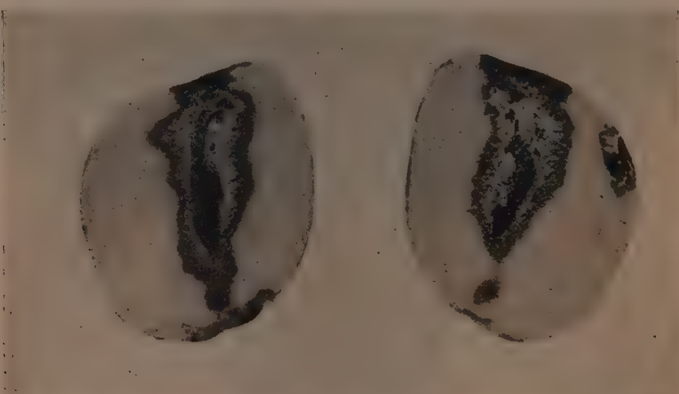

Fig. 8. Black-leg rot in the tuber.

(49, 50) and Morse (40) point out, the disease does not increase when potatoes are grown more than one year in the same soil, if precautions are taken to use healthy seed tubers; on the contrary, the disease may be practically eliminated under these conditions. This has also been the experience on the experimental plots at Charlottetown, where in some cases the same land has been used for four successive crops of potatoes. The consensus of opinion also indicates successful control when proper selection and disinfection of the seed tubers are practised. Morse (39) gives evidence on this point and Coons (20) reports a striking case in northern Michigan in which part of a shipment of seed potatoes which were untreated produced a 75 per cent diseased crop, while another portion which was carefully sorted and treated had only 0·1 per cent of the disease.

The formalin steeping treatment of the tubers (1 pint in 30 gallons of water for two hours) has given uniformly successful results in Prince Edward Island in districts in which by the report of the growers black leg had been generally prevalent for some time. A great deal of evidence is available in this connection.

Although there seems to be considerable reluctance in finally accepting the view that this disease is not, for practical purposes, harboured or spread by the soil, failure to bring about infection from this source and the success of control measures applied to the tubers leave no other alternative open. The scepticism which has prevailed as to the absence of soil infection is to be traced to three or probably four factors: The failure to account for certain widespread outbreaks in plants produced from seed tubers presumed to be practically uninfected; the want of any entirely satisfactory theory of hibernation in the tubers; the failure of attacks to develop in certain cases from infected seed potatoes under conditions presumed favourable; and the possible confusing of *Fusarium*-wilt with blackleg.

The first point may, it is thought, be sufficiently explained by reference to the treatment seed potatoes undergo during and after the operation of cutting. When potatoes are cut in rapid succession and the seed pieces are stored in barrels or heaps, as is usually the case, a great deal of bacterial inoculum would not be required to infect a large proportion of the sets under the conditions of abundant food, heat and moisture which occur. In fact a very few infected potatoes would suffice. If favourable conditions for the parasite follow after planting, outbreaks of the largest proportions recorded might be readily accounted for. Furthermore, variations in the method of cutting and subsequent handling might explain the different behaviour of two lots of the same seed potatoes planted under apparently similar conditions, a feature which is sometimes noted.

METHODS OF SEED TREATMENT

It is obvious that if the seed pieces could be disinfected after cutting much or all of this danger would be eliminated. It would also be unnecessary to select the tubers prior to cutting, or to disinfect the knife in case a rotted potato were cut. Two trials were made in two successive years to see if this course might be safely followed. Unfortunately no blackleg developed in either year in any of the plots, so the success of the treatment in this respect could not be determined. It appears, however, from table 16, that the percentage of misses was increased in both years by disinfecting the sets and that the yield was reduced by an appreciable amount, although no serious damage was done. Several growers who subsequently tried the method report that they could see no damage. It is probable that, in the light of the results of Melhus (36) and Coons (21), the time of treatment might be reduced, in which case the injury should be less. The former author recommends steeping potatoes for two minutes in a solution of 2 pints of 40 per cent formaldehyde in 30 gallons of water, which is kept at a temperature of 118° to 122° F. The wet potatoes are covered in a heap for one hour and then dried. Coons finds that the regular 1:240 formaldehyde steep is effective for common scab and slight *Rhizoctonia* if the potatoes are kept in the solution for fifteen minutes; and that thirty minutes in 1:1000 corrosive sublimate is thoroughly effective against both diseases. It is probable that any of these formulæ would be sufficient to control black leg.

Melhus and Rhodes (37) find that holding wheat for twenty seconds in the vapour of a 1:240 formaldehyde solution in water, which is kept at a temperature of 98° to 99° C., destroys all the fungi and most of the bacteria on the grain. It is evident, therefore, that the customary methods of disinfecting potatoes are unnecessarily drastic. If the modified treatments prove effective after further trial they may be found safe to apply to cut potato seed pieces.

TABLE 16.—Effect of disinfectants for the control of black leg on tubers and cut sets.

Year	Disinfectant	Strength	Duration of treatment	Applied to	Per cent misses	Total per acre
			Hours			Bush.
1916	Corrosive Sublimate	1–2000	3	Tubers	9·5	485
				Sets	17·9	427
	None				12·9	466
	Formalin	1–240	3	Tubers	7·4	463
				Sets	17·7	417½
1917	Corrosive Sublimate	1–2000	3	Tubers	3·5	208
				Sets	5·5	185
	None				3·5	213½
	Formalin	1–240	3	Tubers	4·0	196½
				Sets	9·0	191

The tests were made on a large scale and the high proportion of misses in 1916 was due to the faulty work of a potato planting machine. It is noticeable that formalin injures the sets more on the average than corrosive sublimate. This point appeared more clearly in tests in the laboratory. The failure of a single black leg plant to develop in 1917 is striking, because the seed potatoes used came from a crop which had approximately 50 per cent of the disease in 1915 and 1916, thus emphasizing the dependence of the parasite on external conditions.

INFLUENCE OF THE WEATHER

Black leg is dependent principally on the weather for its appearance, and it is particularly sensitive in this respect. It might be thought that the temperature is sufficiently low and moisture abundant enough in June in any year to cause an outbreak along the Canadian Atlantic seaboard, yet this is not so. Similar potatoes to those used above, which had suffered severely from black leg during the two previous years, were used for a series of experiments in 1917 in which treated and untreated tubers were planted early and late, in dry and wet ground, immediately after cutting and some time after cutting. Only one single black leg plant developed, and that in a place where it would, theoretically, not be expected. As it happened, there was less of the disease in the year selected for the work (1917) than in any season of the five we have been watching it. This is apparently referable to the high temperature in the months of June, July and August (table 17). On the other hand the month of June, 1915, the year of the severe outbreak, had much the lowest temperature of the period, and the same is true to a less extent of July and August. June is evidently the critical month. The amount of precipitation seems to be of secondary importance, but it probably governs the smaller fluctuations in years in which the temperature is fairly high. There also has to be taken into consideration the extent to which infection is present on the seed tubers, this depending on the prevalence of the disease the previous year. It is probable that the moderate attack of 1916 is to be traced to copiously infected seed potatoes, for the year was a comparatively warm one. The slight outbreak of 1918, in which temperature and precipitation were favourable, follows logically from the practical absence of black leg in 1917.

TABLE 17.—Influence of temperature and rainfall on black leg at Charlottetown, P.E.I.

Year	Mean temperature			Precipitation			Approximate amount of blackleg
	June °F.	July °F.	August °F.	June In.	July In.	August In.	
1915	54·7	63·6	63·5	3·1	1·9	2·2	Very severe.
1916	59·2	64·4	65·5	2·7	4·1	1·8	Moderate.
1917	60·2	65·5	68·2	2·5	1·9	4·9	Practically absent.
1918	56·8	65·0	62·1	3·2	4·5	1·4	Slight.
1919	59·2	64·0	63·9	2·2	3·3	4·1	Moderate.

LEAF ROLL

There are few diseases which exert a more disastrous effect on the potato or reduce the yield more than leaf roll. It is fortunate that it is not very widely spread, comparatively speaking, in Canada. In other countries in which it is present more abundantly it has at times raised fears for the success of the industry, as in a considerable portion of northwestern Europe, particularly in Germany, about 1907. These fears were possibly exaggerated, but the loss was real enough in some districts and probably would have been greater if energetic action had not been taken. Even in Canada with the restricted distribution of the disease the damage is considerable, amounting in southern Ontario alone to 10 per cent of the crop, valued at nearly 2¼ million dollars. It seems desirable that potato growers should become more familiar with the disease so as to reduce this loss or prevent it from increasing, for it is apparently not out of the question that the trouble may spread to other parts of the country.

SYMPTOMS

The name leaf roll is rather unfortunate because it emphasizes a character which is not generally conspicuous and which is more marked in other diseases such as wilt, little potato (*Rhizoctonia*) and black leg. Rolling of the lower leaves is, however, the most constant symptom of leaf roll and the one by which it is most easily recognized.

Diseased plants are most conspicuous in comparatively early stages, about one month after they come up, although the disease is sometimes evident just as soon as the leaves appear. More usually the plants seem to be normal for several weeks, when the diseased appearance is assumed with considerable suddenness. The best time to examine a field is at the period, before the healthy plants have had time to cover up the weaker. The disease may still be found, however, at a later stage although with more difficulty. Still later it is inadvisable to attempt to determine leaf roll with certainty.

The typical leaf roll specimen is a somewhat stocky, dwarfed plant with the tips and margins of the lower leaves rolled upwards into the shape of a shallow spoon, or sometimes almost into the shape of a cylinder. All the leaves but the lower ones may be normal, and frequently not even all the latter are involved. In other cases the upper leaves may show considerable rolling, particularly as the season advances (72).

The rolled leaves are distinctly harsh, brittle and leathery to the touch. If one of them be broken across it can be seen with the naked eye to be thicker than a healthy leaf. As the disease progresses the tips of the rolled leaves become yellow and later brown, and red or purplish areas may develop on them, and also some-

times on the upper leaves. On account of the abnormal rigidity and partial drying-out, a kind of rattling sound may be produced when a rolled leaf is brushed with the hand.

Diseased plants are always smaller than neighbouring healthy ones, generally very noticeably so. The colour of the foliage is usually a light green, sometimes approaching yellow. This varies somewhat with the variety, as in some sorts, Early Puritan, for example, the normal green shade is not appreciably reduced by the disease. Certain varieties present the appearance of faint alternate bands of green and yellow running from the midrib to the leaf margin. This feature is often found in Garnet Chili and Empire State. In this and in some other ways the symptoms

Fig. 9. Leaf roll in Early Ohio.

vary somewhat with the particular potatoes under observation, and also probably with the season and soil conditions. Possibly in the majority of cases diseased plants have a stiff, upright form of growth, but a low-headed spreading habit is generally found in certain varieties like Early Puritan and many others.

The yield is a good distinguishing character. There are few diseases which reduce the crop as much as leaf roll, and such as there are do not occur with the same frequency in Canada. The yield of leaf roll plants is generally only one-quarter to one-third of that of healthy plants. The way in which the tubers are borne on short stolons or almost directly attached to the stem is also characteristic. The potatoes, though generally small, are normal in appearance, no rot being produced in them or indeed in any part of the plant. The set from which a diseased plant springs commonly remains firm until the end of the season. This is not an invariable rule, however, and its occurrence is not confined to leaf roll alone.

It is difficult to present in words an accurate picture of this disease, partly because the features which are constantly associated with it are not of an outstanding nature, and partly because the diagnosis rests on a combination of characters some of which may be absent. Once the type is grasped, however, it will be realized that there is a uniformity underlying all affected plants, and that one can in the great majority of cases, and even with a casual examination, readily say whether or not

any individual specimen is diseased. This can only be accomplished by experience gained in the field, but the plates showing examples of the disease will also be helpful.

The most frequent source of error lies in too hastily assuming that all plants exhibiting rolling of the leaves are cases of leaf roll. It is normal in some varieties for all the leaves to roll, in others the top leaves are commonly rolled, while in still others natural rolling is confined to those next the ground. A too critical examination of the lower leaves will sometimes lead one to suppose that the whole crop is diseased when such is generally not the case. Potatoes diseased to the extent of 100 per cent are comparatively rare. In circumstances like these, though the lower leaves may be generally rolled, the leathery feeling is absent and the leaves are not dead at the tip as a general rule, or if they be dying, they will be found to be quite limp. The whole plant is of a good green colour without the stiff habit most often associated with leaf roll. Here again the yield is a good guide for the beginner.

A considerable number of large, vigorous plants, generally of a comparatively healthy colour, frequently show rolling of the topmost leaves, particularly towards the end of the season, due to a variety of causes of which the little potato disease (*Rhizoctonia*) is the commonest. The yield of these plants will generally be found fairly satisfactory, although it may consist of many very small potatoes, and it may be assumed that they are not affected with leaf roll. There is little possibility of confusing leaf roll with black leg, attacks of the stem borer, mechanical injuries to the stem, particularly if the plant be pulled up, or even with the wilt disease. The latter are like black leg in their effect on the foliage; while the leaves may be conspicuously rolled they become so limp from lack of water that there is not much danger of their being long mistaken for the stiff rolling of true leaf roll. They are, besides, comparatively rare in Eastern Canada.

Perhaps the chief danger in this connection lies in those obscure manifestations of an unfavourable soil condition which cause a weakening of the plant accompanied by rolling of the leaves, and, if long continued, a more or less marked reduction in yield. Improper moisture conditions in the soil are a frequent source of this appearance, and, as might be expected, the affected areas are often localized, being confined to depressions in the field perhaps. When this is found to occur one is, in the great majority of cases, not dealing with leaf roll, which is normally found distributed all over the crop. Evidences of mal-nutrition may also be distinguished by the fact that they are of a temporary or seasonal duration and disappear along with the conditions which give rise to them. In difficult cases perhaps the ultimate criterion is to replant tubers from suspected plants under as favourable conditions as possible, and if the same leaf roll-like symptoms are reproduced it is a satisfactory indication that the disease is present.

GEOGRAPHICAL DISTRIBUTION AND CLIMATIC RELATIONS

Whatever may be the immediate cause of leaf roll it is certain that climate and the other factors which make up the plant's environment are of great importance as predisposing causes of the disease.

The influence of environment is emphasized by a study of the general situation in Canada. The Maritime Provinces are, with slight exceptions, practically free from the disease. The same holds true for the potato-producing counties of central Quebec and northern Maine. As ones goes further west, leaf roll begins to appear in appreciable quantities in the neighbourhood of Montreal. The maximum infection is found in considerable areas of Old Ontario, particularly to the south near the lakes, while some of the commercial districts further inland are probably not seriously involved. The same situation exists in New York state, where the western counties bordering on lakes Erie and Ontario are most severely affected. This is most probably to be explained by assuming that the climate of the lake region is peculiarly favourable to the disease. The cooler northern portions of Ontario are as free from infection as the

Maritime Provinces. In the Prairie Provinces the disease does not seem to be so generally serious. Crops which are more or less badly affected may be found in the market gardens near Winnipeg, Brandon and other cities, but it is believed that they do not represent the average, as some of the stock at least is imported. The situation in Alberta and British Columbia has not been investigated.

The prevalence of the disease in any district can probably be referred to four factors, presence of infection, suitable climate, susceptible varieties or infected seed potatoes. Since leaf roll has been shown to be an infectious disease the presence of the causal agent must be assumed in every case, and outbreaks cannot be referred to weather or soil conditions or other environmental factors alone. The importance of climate as a predisposing cause is, however, apparently great, as the distribution of leaf roll in the Dominion shows. There are some climates in which, granted that infection is present, the disease is at home and spreads to such an extent that healthy potatoes invariably become contaminated sooner or later. Bermuda is an outstanding

Fig. 10. Distribution of leaf roll in southern Ontario.

example, but the same thing occurs in parts of Old Ontario. In such places the disease seems to be endemic. In other parts of the country, where infection is not so general, outbreaks are often traceable to the importation of infected seed potatoes and are referable to a smaller extent to the climate. Several instances were seen near Winnipeg in which it was reasonably certain that leaf roll arose from the purchase for seed purposes of early southern potatoes on the Winnipeg market. In one such case more than ninety per cent of the crop had leaf roll. The same thing sometimes occurs in the east from the misguided enthusiams of southern planters, who having got seed stock which they like, send some of the crop back to be propagated in the north. This has happened on more than one occasion in Nova Scotia with results which involved whole districts. It is also clear that varieties vary greatly in their reaction to leaf roll and that the growing of susceptible sorts aggravates the situation. This matter will be dealt with later.

CAUSE OF LEAF ROLL

The immediate cause of leaf roll has long been in doubt and the question is not yet decided. Various attempts (10, 45) have been made, principally in Germany, to correlate outbreaks of the disease with forms of disturbance of nutrition, bad culture and weather conditions. Among these may be mentioned: the lack of mineral elements in the soil such as potash; superabundance of the same elements; use of mature seed potatoes, and again the use of immature tubers; using potatoes from prematurely ripened plants; lack of seed selection; continuous vegetative propagation; varietal deterioration; drouth; sandy soil; and incorrect cultural practices. No convincing proof has been adduced in support of any of these theories. Indeed since Quanjer (55) showed that the disease is infectious none of the conditions can be the primary cause. As the work of this author is not readily available it will be well to summarize his infection experiments here.

INFECTION EXPERIMENTS OF QUANJER, VAN DER LEK AND OORTWIJN BOTJES

(1) Healthy plants of élite stock were infected by growing them near potatoes in which leaf roll was prevalent, while the same stock remained healthy when grown in isolation.

(2) Diseased stocks and scions conveyed the disease to the portions of healthy plants to which they were grafted. The disease appeared first and most severely on the parts of the healthy tissue nearest the graft and gradually spread from there all over the plant, even into other healthy stems springing from the same tuber where the stock was healthy and the scion diseased. Control plants remained healthy. Slightly diseased scions when grafted on a susceptible variety developed more pronounced symptoms of leaf roll than when grafted on a resistant variety.

The attempt to transmit infection by injections of sap from diseased plants and by inserting particles of diseased tissue in the stalks of healthy plants was a failure. If, however, diseased scions were cut off close to the graft after union had taken place, infection followed. Tomatoes grafted with diseased potato tissue remained healthy and exerted a favourable influence on the scions.

(3) The attaching of the halves of diseased tubers, which had been deprived of their eyes, to the halves of healthy tubers in such a way that organic union took place, resulted in the shoots derived from the originally healthy sets becoming diseased. The corresponding halves of the leaf roll and healthy tubers when planted in separate rows gave rise to leaf roll and healthy plants respectively.

(4) Soil which grew a crop of potatoes in which leaf roll had been prevalent the previous year produced a crop entirely and severely diseased the following year from healthy seed tubers. Two plots, both of which had grown partly diseased potatoes in 1909, 1911 and 1912, produced from healthy seed potatoes in 1915 crops which were 100 per cent and 89 per cent diseased respectively. Parts of the same tubers used in above experiments when planted in soil which had not been in potatoes for twenty years produced a crop which remained healthy until September, when four plants (20 per cent) at one end of the row near infected soil developed slight leaf roll.

In another experiment in 1915 tubers were cut into eight sets which were planted in as many plots, one not having had potatoes for five years and another for four years, a third being similar but having the stalks of diseased plants dug into it, a fourth having raised a diseased crop in 1910 and 1912, a fifth having raised a diseased crop in 1911 and 1913, a sixth having had a diseased crop in 1911, 1912 and 1914, and a seventh and eight in 1914 only. All the plants became diseased, the attack being most severe in the last three plots and least so in the first two. Soil infection, it is concluded, can persist five years, especially when little or no cultivation is done, as was the case here, these plots having previously been in ornamental shrubs and gooseberries.

(5) The progeny of ten hill units which were partly diseased and partly healthy in 1913 were further followed individually in 1914. The disease spread further in the partly diseased units, and those plants of healthy units which were nearest to affected plants contracted the disease, the infection being said to spread one to two metres.

In a further experiment in 1914 part of the tubers from a healthy plant were put in between two rows of diseased plants, and part near healthy plants. The former produced 91 per cent of leaf roll plants and the latter 97 per cent of healthy plants, the six plants in this lot which showed disease being traced to accidental infection.

(6) "A rather high percentage of diseased plants was present amongst the seedlings of diseased parents, whereas a rather low percentage was present amongst the seedlings of sound ancestors." The results are not considered conclusive owing to possible soil infection and other complications.

The account of these experiments is accompanied by photographs which leave little room for doubt as to their correctness. It should be noted, however, that in most of the experiments the diagnosis seems to have been based on the "primary stage" of leaf roll, although in some cases mention is made of this being confirmed by microscopic examination for phloëm-necrosis. It is evident from the photographs that this so-called primary stage may be very pronounced in Holland. It is not present to any regular extent, if at all, in Canada, and it would be impossible or very unsafe to base the diagnosis on it here. It is believed that it would be preferable to rely more on the secondary stage even when a primary is present. Since, however, Quanjer's results have been amply confirmed in the important matter of neighbour infection, as will be shown, there seems to be no reason to question the validity of the remaining conclusions under the conditions of the experiments.

These discoveries point to the cause of leaf roll being either a living organism, a virus, or a toxic product of deranged metabolism of the plant itself which is capable of regenerating itself when introduced into healthy plants. No light has yet been thrown on its nature. Quanjer looks on the degeneration of the phloëm (channels for the conduct of elaborated material downwards from the leaves) as the work of this organism, virus or toxic product, and therefore suggests the name phloëm-

necrosis for the disease instead of leaf roll. This author (54) was the first to discover that the phloëm of leaf roll plants was abnormal, and in this way was responsible for the first forward step in elucidating the nature of the disease. In (secondarily) diseased plants the tissues are said to remain healthy until the symptoms of leaf roll appear, usually several weeks after the plants come up. Then the phloëm from the base of the plant upwards shows signs of disintegration. The cell walls become swollen and collapse, obliterating the cavity. At the same time a yellowish colour is developed and the walls become lignified. The most pronounced necrosis is found in the base of the stalks of the lower rolled leaves, while it is absent from the smaller veins of the leaflets, the rhizomes, tubers and roots. In primarily diseased plants the necrosis is said to be less marked and to be confined to the upper rolled leaves.

Fig. 11. Healthy and rolled leaves of Irish Cobbler.

Quanjer's position has been challenged by various German and Austrian authors. Schander and Tiesenhausen (61) state that necrosis of the phloëm is also found in other diseases, such as curly dwarf, and that it may be present or induced in healthy plants. As to the former point we have found in our work that a severe necrosis which may involve all the tissues is found in more than one disease. Artschwager (11) in a recent paper has also failed to find a regular relation between the external symptoms of leaf roll and necrotic phloëm and is of the opinion that the necrosis is not always sufficient to account for the severity of the disease. While there is, therefore, room for doubt whether the necrosis of the phloëm is the cause of leaf roll or only an effect, the evidence points to Quanjer being correct in associating a specific form of necrosis with the disease.

PERMANENT NATURE OF LEAF ROLL

The opinion is frequently held that plants become progressively weaker with leaf roll and finally tend to die out. With the exception of Quanjer's "primary stage,"

which appears to be non-existent or very unimportant in Canada, this is not so. Once the stage is reached which is designated "leaf roll" in this country ("secondary leaf-roll" of Quanjer), there is no progressive diminution in vigour and yield, nor any permanent improvement so far as our experience has gone, although the size of the plants and the crop may fluctuate considerably. Most of the experiments now to be recorded, unless otherwise noted, were carried out at the Experimental Station, Charlottetown, P.E.I., under very favourable conditions for growing healthy potatoes.

A number of strains of leaf roll potatoes have been grown for five years at Charlottetown in order to see if recovery takes place. This has not occurred. The plants now present just the same appearance as when they were first selected in 1915, or later, and a healthy individual has never been recorded in the collection. The yields for the five years under review are given in table 18.

TABLE 18.—Yield of leaf roll strains for five years or less at Charlottetown, P.E.I.

Strain	Average yield per plant in oz.				
	1915	1916	1917	1918	1919
15	10·0	0·6	2·4	3·0	2·0
16	3·0	1·1	4·8	3·8	3·0
17	4·0	0·9	6·9	15·7	4·2
32	6·0	3·1	5·4	7·2	4·0
45–49	....	1·8	4·3	3·0	....
P 20 C	....	....	4·9	7·6	2·1
P 20 G	....	....	3·5	4·0	3·6

The low yield in 1916 was accompanied by a reduction in vigour, and both were probably due to poor soil conditions. The high yield of strain 17 in 1918 is to be noted and compared with the yields in the years before and after that date. The potato crop was generally a heavy one in 1918 and it must be assumed that this influenced the result. The yield of the leaf roll strains is again down in 1919. It is thus seen that diseased plants may respond to unfavourable or favourable conditions, in fact to a greater extent than healthy plants, as where growth is very luxuriant the yield of the former seems to approach nearer to the normal (even though that is high) than where growth is moderate or poor. This fact sometimes leads to a mistaken view on the part of growers that the disease has been thrown off. An unequivocal case of recovery has never come to our experience. Many instances of recovery on large and small scales have been given, and it is unquestionable that run-out seed potatoes do regain their vigour under certain circumstances. This has happened to some extent in the Greeley district of Colorado, where in a few bad years culminating in 1911 and 1912 (45) the output of potatoes was reduced from an estimated 7,000 cars to 200 cars, while since then the losses have been light (31). Still more striking cases of recovery are furnished by Macoun (32), who finds that seed potatoes which have run out almost to the point of extinction at Ottawa recover their vigour when grown for one, two or three years in the Prairie Provinces, and also to some extent in the Maritime Provinces. The recovery is indeed very striking in the former case. The yield the first year the potatoes are sent out of Ontario has been as low as 20 bushels per acre, yet after being grown in Western Canada for a short period the vigour and yield are said in most cases to return to normal. None of the authors who record these facts attributes the degeneration to leaf roll, or the recovery to the throwing off of this disease, but that assumption is the one that is generally made by commentators. It is idle now to speculate on the cause of the Colorado trouble from 1908 to 1912, but the recent work of MacMillan on *Fusarium* blight raises the possibility that this disease was responsible. With respect to the Ottawa potatoes it has since been learned that leaf roll is not the major factor in their degeneration, certain other obscure diseases being present to a greater extent. If leaf roll is really thrown

off, the fact will never be proved unless authentic material is used, and the behaviour of individual plants is followed year after year. The term recovery as applied to an individual plant, and as applied to an increase of vigour of potatoes in the bulk, may be used in different senses. In the latter case the elimination, natural or otherwise, of diseased plants might effect an improvement in the general vigour without any actual recovery having taken place.

RELATION BETWEEN THE YIELDS OF LEAF ROLL AND HEALTHY PLANTS

There is a fairly constant relation between the yields of leaf roll and healthy plants grown under the same conditions, as experiments conducted in Charlottetown in the years 1917 to 1919 show. The yield of a diseased plant is generally not much higher than 33 per cent, or lower than 20 per cent, of the normal in Prince Edward Island. Occasionally the yield of leaf roll may drop to only 5 per cent, while on occasion it may rise to 55 per cent of the yield of healthy plants. Generally speaking the ratio is fairly constant for all varieties at the same place in the same season, but it varies considerably from one year to another. This will be clear from reference to table 19.

TABLE 19.—Comparative yields of leaf roll and healthy plants of the same variety

Year	No. of tests	No. of varieties tested	Average yield per plant		Leaf roll yield as percentage of healthy
			Leaf roll	Healthy	
			oz.	oz.	
1917	6	19	6·8	20·3	33·5
1918	22	8	5·7	31·2	18·3
1919	15	11	4·7	23·6	20·0

The locality in which the crop is grown seems to have a considerable influence on the productive power of diseased plants. In the year 1918 uniform seed potatoes, both leaf roll and healthy, of the variety Empire State, were planted side by side in nine different places, one being in Prince Edward Island, two in Nova Scotia, one in New Brunswick, one in Quebec, two in Ontario, one in Manitoba, and one in Saskatchewan. The yields are shown in fig. 12, together with a record of the temperature during the early part of the season. Naturally the yields varied greatly, it being impossible to make all the soil and cultural conditions uniform, not to speak of the weather. Under these circumstances the relative yields of the leaf roll and healthy plants form the best standard for judging the reaction of leaf roll to its environment. This is shown in the lowest line (dot and dash) in the figure.

It will be seen at a glance that there is a direct relation between the yields of leaf roll and healthy plants at the same place, with the exception of Thunder Bay, Ont., where the diseased plants gave a conspicuously poor crop. It should also be noted that owing to an accident the leaf roll plots failed at Indian Head. There are three places where the diseased potatoes gave outstandingly high yields, these being in descending order, Brandon, Man., Ottawa, Ont., and Kentville, N.S. At the same places the yield of the leaf roll plants approached much nearer to that of the healthy plants than elsewhere, and this was not because the healthy crops were poor, for they were in fact among the largest, along with Nappan, N.S., and Thunder Bay, Ont. It is difficult to find a factor to co-ordinate the results at three places so far apart and so different as Manitoba, southern Ontario and the fruit district of Nova Scotia, yet it does not seem to be an accident that leaf roll plants reacted similarly

at these three stations, for it will be seen by reference to figure 22 that in a similar experiment with mosaic the highest yields from diseased potatoes were obtained at the same three stations in the same order.

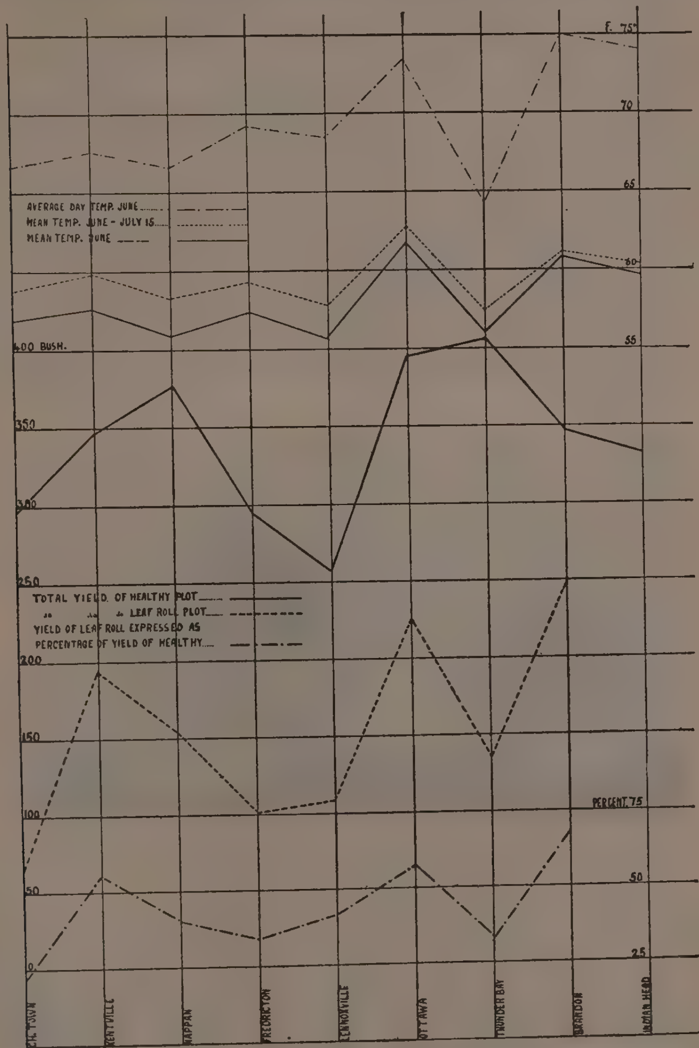

Fig. 12. Influence of locality and climate on the yield of leaf roll and healthy plants (Uniform Empire State seed throughout).

There was, generally speaking, a comparatively poor crop from both healthy and diseased potatoes in all the experiments in the better potato districts of the Maritime Provinces and Quebec (Charlottetown, Nappan, Fredericton and Lennoxville). This is probably attributable to wet and cold weather, particularly early in the season. At Thunder Bay, the centre of another good potato district, an exceptional result was obtained, in that the healthy plot yielded exceptionally well while the leaf roll plot

yielded poorly. In the other three places, which would not normally be considered as favourable for potato production as the localities just mentioned, the yield of the leaf roll plants was conspicuously high, and that of the healthy plants among the highest also. It might be concluded from this that the conditions which caused healthy plants to produce large crops in 1918 in the latter districts reacted to an even greater extent on leaf roll plants, resulting in a much higher yield than the same seed produced elsewhere.

When one seeks to analyze what these conditions were, serious difficulty is met. It is probable that there was no serious lack of water anywhere with the exception of Indian Head (which is practically excluded from the experiment). The nearest to a shortage was found at Brandon, Man. After that the places most subject to drought were probably Ottawa and Kentville, but they suffered in no way in 1918. Apart from mentioning that Fredericton and Lennoxville had too much rain in July, the precipitation may be dismissed as being fairly uniform and sufficient. Turning to the temperature during the first half of the growing season, it seems that there is found here for the most part a direct relationship between the mean temperature and the ratio of the yield of leaf roll and healthy plants, the highest mean temperatures from June 1 to July 15 being found at Ottawa, Brandon and Kentville, and the largest crops from leaf roll seed, relatively and absolutely, at the same places though not in the same order.

Fig. 13. Effect of leaf roll at Charlottetown. The healthy plants yielded just three times as much as the diseased.

As has been stated, the same relation is found to hold between the yield of potatoes diseased with mosaic and the temperature. In this case a large yield from diseased plants is at least in some cases, and possibly in all, associated with a diminution or suppression of the symptoms of the disease. There is considerable evidence that the intensity of the symptoms of mosaic is a direct result of the temperature, particularly during the early part of the season, cold weather aggravating the severity of the disease. This adds a certain amount of circumstantial evidence that the relation found in the experiment between high temperature and large yield of leaf roll plants is one of cause and effect.

While it seems likely that, other things being equal, there is a direct relationship between the yield of diseased potatoes and the temperature, it became evident from the continuation of this work in 1919 that other factors may be of as great or greater importance. The climatic conditions were not nearly so uniform in that year. Extreme drought was experienced at Indian Head, Brandon, Thunder Bay, and Ottawa. Farther east conditions were more uniform but the yields varied very

greatly at the different stations. Furthermore, the spread of leaf roll in the plots (this being the principal object of the work) made the results so far as the healthy plants go more fragmentary. Another factor entered in also which must not be overlooked in treating of the influence of diseases on seed potatoes, that is the "place-effect".

The results discussed up to the present were obtained from potatoes which were sent from Charlottetown to every station for the special purpose of this experiment, and which were, therefore, as uniform as possible. In the continuation of the experiment in the second year each station made use of seed potatoes saved from its own plots of this original Charlottetown seed. The magnitude of the effect on the yield of one year's growth under the different conditions would not have been realized but that samples from most of the stations were sent back to Charlottetown and grown there. Some of these potatoes were still quite healthy or contained less than 0·5 per cent of any disease. The result of a six-fold test of such potatoes belonging to three varieties is shown in table 20, column 2. A small single plot test was also made of leaf roll and mosaic potatoes from the same stations. These were also originally uniform, the former being all derived one year before from southern Ontario and the latter from Charlottetown. So far as a conclusion can be drawn it would seem that diseased plants do not respond to place effect in the same way or to the same extent as healthy potatoes.

TABLE 20.—Place-effect on originally uniform healthy and diseased potatoes after one year's growth at various stations

Place in which grown for one year	Yield in pounds when returned to Charlottetown		
	Healthy potatoes. Average of 6 plots of 3 varieties	Mosaic potatoes. One variety	Leaf roll potatoes. One variety
Kentville, N.S.	33	37½	10
Nappan, N.S.	34	38	11
Fredericton, N.B.	34	37½	13
Brandon, Man.	47	31	12
Indian Head, Sask.	43	27½	..

(No potatoes were available from Lennoxville, Ottawa or Thunder Bay.)

The maximum difference observed between two lots of the same healthy seed potatoes brought back to their point of origin after being grown in the one case in the Maritime Provinces (Kentville, Nappan, Fredericton), and in the other case in the Prairie Provinces (Brandon, Indian Head), is practically 30 per cent, equivalent approximately to 160 bushels per acre in this experiment. It will be noted that the prairies have a very good after-effect on the healthy potatoes, but apparently the reverse on mosaic plants, notwithstanding the unusually vigorous appearance of the latter while being grown in the west.

It is clear, therefore, that the result of place effect alone introduces a considerable complication, because the seed potatoes can no longer be considered uniform. Combined with the weather and varying soil fertility, it helps to explain the great variations in the yield of leaf roll and healthy plants, and in the relation of these to each other, which were found in 1919. These differences are so great that it is difficult or impossible to interpret the results. One point, however, is fairly clear, namely, that, as in the previous year, the highest relative yields from leaf roll plants were found at Ottawa and Brandon where the temperature was also highest.

While no final conclusion can be drawn as to the effect of climate on the disease, it is evident that this effect is considerable and there is some proof that temperature

is directly concerned. Besides temperature there are, however, further influences such as water supply, soil fertility, possibly source of seed and other factors, all of which are inter-related in a manner which has not been made clear. Acting together they bring about differences in the productive power of diseased seed potatoes, so that in one place they return as much as 75 per cent, and in other places only 27 per cent of the yield of healthy plants.

The figures just given do not represent the total loss which results from leaf roll. A diseased crop has a smaller run of marketable potatoes, the percentage varying from about 33 per cent marketable in the worst cases to 50 or 60 per cent, which is the average figure, and rising to 80 per cent in those cases in which leaf roll plants produce a comparatively large crop. In the experiment just described the percentage of the crop marketable at Brandon was 82 per cent, at Ottawa 71 per cent, and at Charlottetown 56 per cent. The corresponding figures for the healthy plots were 97, 92, and 86 per cent respectively.

THE MEANS BY WHICH LEAF ROLL IS PROPAGATED

All authorities who have carefully studied the matter and who worked with authentic material agree that tubers from leaf roll plants always carry the infection and give rise to a diseased plant again. Among these may be mentioned Appel (10), Orton (45), Quanjer (55), and Wortley (72). This also has been our experience in experiments some of which extend over five years (cf. table 18). It may, therefore, be stated that a case of recovery has never been proved, and that the tubers from affected plants may be expected to carry the disease. It should be noted, however, that all our experiments on this point were carried out at Charlottetown, P.E.I. The climate there is favourable to potato production, and leaf roll is practically absent in commercial fields. Under these circumstances recovery might be expected to take place

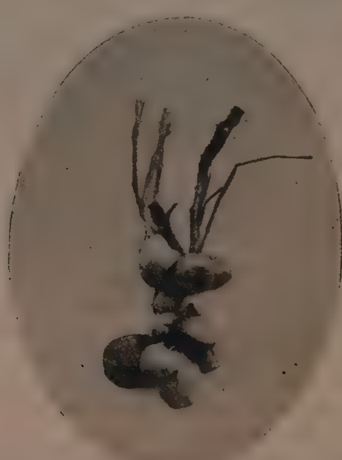

Fig. 14. Close set of tubers in leaf roll and persistence of old set (to left).

if it occurs at all. At the same time it has been found that climate has a considerable influence on leaf roll, as has been shown, and it would be unwise to generalize too far beyond the conditions of our observations and those of others, which, however, cover Germany, various parts of the United States, Holland, Bermuda, and Prince Edward Island. It must remain a matter for speculation what the ultimate effect on the disease would be of growing affected potatoes for a period of years at such a

place as Brandon, assuming that the plants continued to produce as well, and that infection was not conveyed from plant to plant, as was the case in our experimental work there.

The tubers were the only known agents of propagation until 1916. When work was first begun in 1915 in the affected area of Nova Scotia it was believed that leaf roll should in time eliminate itself since the diseased plants produced about one-third of a crop. The then general view was also held that the selection of seed tubers from the largest and healthiest plants would hasten this process materially. Experiment and observation proved both of these views erroneous.

A scheme of seed potato selection on a large scale was begun in co-operation with the Garnet Chili growers in King's county, N.S., where leaf roll was very common and was jeopardizing the seed trade with Bermuda. Things had come to such a pass that the Bermuda Government had arranged for the transfer of some of the best stock to Maine with the purpose of drawing its supply from there. The Nova Scotia growers were thoroughly alarmed and willingly undertook any method that promised a way out. In the Church Street district thirteen of the growers who had the best crops selected by hand from one-half barrel to fifteen barrels of potatoes from the largest plants in their fields and planted them in 1916 beside potatoes from the general crop. The result was so far from expectation that it was difficult to explain on the old theory of the nature of leaf roll, for there was on the average almost as much of the disease in the selected as in the unselected lots. For example, one grower had 41 per cent of leaf roll in his selected potatoes while another had 25 per cent. Although proof was thus given for the first time that the selection of large plants from a crop affected with leaf roll will not get rid of the disease, a further attempt was made in 1916 to improve large areas of potatoes intended for planting in Bermuda by pulling out the leaf roll plants. The result was again the same, for a high percentage of leaf roll developed in these stocks in the south.

It was at this time that Quanjer's (55) paper came to our attention in which the infectious nature of the leaf roll seemed to be proved. The same phenomenon was at that very time taking place in our hands, for potatoes from one of the selected plots just mentioned which gave 25 per cent of leaf roll in 1916 gave 40 per cent in 1917. Quanjer's theory was immediately put to the test under strictly controlled conditions, with the result that it was confirmed (42). Healthy potatoes of the variety Garnet Chili which were exposed to infection in 1916 by being grown beside leaf roll plants developed 89.5 per cent of the disease the following year, while similar potatoes grown in the same plot but removed a distance of eight rows from leaf roll produced an entirely healthy crop in 1916 and 1917. The diseased stock has remained diseased to date, that is for three years, and some of the healthy has remained healthy where it was sufficiently isolated. The average yield per plant of this stock was in 1916, while it was still healthy, 24·4 ounce, and the yields for the three years following, after it became diseased, were 4·9 ounce, 7·6 ounce and 2·1 ounce respectively.

This experiment has been repeated every year since with the same general result. Healthy Garnet Chili potatoes which were grown between rows of leaf roll plants in 1917 developed 62.4 per cent of the disease in 1918. Healthy plants grown in isolation in the same plot remained healthy. The same variety developed 50.0 per cent of leaf roll through being exposed to infection in a similar way in 1918, again with healthy checks. Ten other varieties were also tested at the same time with the result that 26.2 per cent of the disease developed on the average.

TABLE 21.—Infection of healthy potatoes with leaf roll by growing them beside diseased plants.

Variety	Year in which exposed to infection	Per cent leaf roll			Checks not exposed to infection; per cent leaf roll	
		1st year	2nd year	3rd year	1st year	2nd year
Garnet Chili	1916	0	89·5	100	0	0
Garnet Chili	1917	0	62·4	86	0	0
Garnet Chili	1918	0	50·0	....	0	0
Ten varieties	1918	0	26·2	....	0	0

Apart from these set experiments the spread of leaf roll from infected to neighbouring healthy plants has been observed so many times that there is no longer any reason to doubt its occurrence. The ground was taken in 1916 that if the transfer really took place the disease should appear all over our plots in the following year owing to the way in which leaf roll stocks were interspersed with healthy. This happened, just as had been feared, both in 1916 and 1917 (when steps were taken to curtail it), and provided a mass of data a small part of which is presented in table 22. The spreading of the disease was very unfortunate because it ruined most of our experiments, such as attempts to produce leaf roll by drouth, poor soil, using small seed tubers from a slightly affected crop, various methods of keeping seed potatoes, seed selection, comparison of strains for susceptibility, and many others. It is at least clear that under Charlottetown conditions, if these factors have any influence, which appears unlikely, they are entirely overshadowed by neighbour infection and the propagation of the disease by tubers from infected plants. It is rather interesting that the only lots of originally healthy Garnet Chili, which were imported from Nova Scotia for planting in 1916 and 1917, which have remained entirely healthy to date (1919) are two samples which were subjected to the worst conditions we could devise for three successive years, by being grown in one case in a long box raised about two feet above the ground so as to be subject to drouth, and in the other in very poor subsoil in which hardly any growth was made. The nature of the experiments made it necessary to place them in isolated corners so as not to impede cultivation and this is the explanation of the absence of disease.

TABLF 22.—Involuntary spread of leaf roll through the experimental plots at Charlottetown in 1917-18

Seed Stock	Variety	Per cent leaf roll in 1917	Average per cent leaf roll on both sides in 1917			Per cent leaf roll in 1918	Per cent leaf roll in 1918 in plots of same seed isolated in 1917
			1 row away	2 rows away	3 rows away		
Chase R 18	Garnet	0·0	28·5	37·9	37·9	100·0	....
Logan P20F6	Garnet	0·0	47·9	50·0	25·0	95·5	0·0
P20F1. R 1	Garnet	0·0	50·0	7·9	43·5	78·9	....
Chase R 37	Garnet	0·0	3·5	14·5	26·3	75·0	....
Logan 1915. P20F6	Garnet	0·0	26·5	16·3	30·0	70·2	....
Armstrong P20B	Garnet	0·0	89·5	0·0	50·0	62·4	0·0
Arm. small P20F6	Garnet	0·0	0·0	26·6	64·1	56·0	0·0
Arm. large P20F6	Garnet	0·0	0·0	47·8	76·6	52·2	0·0
P10F. R 1	C. Pride	0·0	46·6	45·6	50·0	96·0	20·6
P10F. R 2	C. Pride	0·0	0·0	46·6	45·6	80·0	20·6
P10F. R 3	G. Mountain	0·0	0·0	0·0	46·6	16·6	3·6
Selections (G.M.)	G. Mountain	0·0	50·0	50·0	50·0	16·7	5·5
P10C R 64	Garnet	1·6	2·8	5·8	4·8	18·2	0·0
P20F8 R 59	Garnet	4·2	34·3	36·1	29·6	70·0	....
P10C R 67	Garnet	6·0	47·9	1·8	0·8	66·6	0·0
P20F5 small	Garnet	8·5	56·2	72·5	30·5	79·1	....
Chase R 29	Garnet	83·3	50·0	50·0	50·0	100·0	....

These results supplied a full explanation of the failure to improve the crop in Nova Scotia by the selection method being used. When a plant is grown near the disease and contracts infection, there is, in our experience, no sign of the fact in the foliage nor any striking reduction in yield. Careful experiments with 588 plants in 1917, 1918, and 1919 show that a healthy plant which has become infected yields at the rate of 93 per cent of a healthy plant grown in comparable surroundings which has not become infected. If, however, the newly infected plant immediately adjoins a leaf roll plant, the yield, instead of being below normal to the extent of 7 per cent, is 17 per cent above it, because its weak neighbour gives it so much more room to develop. This is more or less along the line developed by Stewart (66) and confirms his findings to some extent. A statement which appears here and there in the literature of the subject, that the first sign of leaf roll is an increase in the yield, which is not true as shown above, is probably referable to the fact that many plants which become infected are adjacent to diseased ones. It will, therefore, be seen that it is practically impossible to detect newly-infected plants in the field, and when it is mentioned that the selections were made from crops containing from a trace of leaf roll up to nearly 50 per cent of the disease, the results could not have been any different. It should be mentioned, however, that other means were found which radically improved the situation, that is the wholesale introduction of disease-free seed potatoes to replace the old.

INFLUENCE OF LOCALITY ON THE SPREAD OF LEAF ROLL IN THE FIELD

An experiment was begun in 1917 in co-operation with Mr. E. J. Wortley, Director of Agriculture for Bermuda, to test the effect of the climate of Prince Edward Island, Bermuda, and southern Ontario on the development of leaf roll. A crop of Garnet Chili potatoes was selected in Nova Scotia in 1916 which had a considerable percentage of leaf roll, and 238 individual plants were dug which yielded three or more tubers. The tubers from each plant were given the same number and one of each was sent to Charlottetown, Bermuda, and Ottawa, where they were planted in tuber units. The results are shown in table 23. As there was considerable loss from rot and other causes, about half of the plants were not represented at Ottawa, but there was practically a full muster in Charlottetown and Bermuda.

TABLE 23.—Result of planting sister tubers from a partly diseased crop in Prince Edward Island, Bermuda, and southern Ontario

—	Number of plants	Cases in which plants reacted similarly at all places	
		Number	Per cent
Plants represented in three places	102	93	91·2
Plants represented in two places	222	208	93·7

This result is rather striking, emphasizing as it does the importance of the tubers as carriers of leaf roll. Comparing Bermuda, which is very liable to the disease, and Prince Edward Island, which is naturally free from it, it is found that only 14 plants out of 222 failed to react similarly at both places. Five of these were leaf roll at Charlottetown and healthy at Bermuda, while nine were healthy at Charlottetown and leaf roll in Bermuda. It is not believed that there was any difference in diagnosis, nor is it likely that the plants became infected locally and showed the disease the same year. It is more likely that the difference existed in the parent plant, because it is not infrequent to find healthy and affected sister tubers in a

partially diseased crop, these being the product of plants, which, while still healthy looking, are in process of contracting infection. Thus it appears from this experiment that where leaf roll occurs it is to be traced almost altogether, if not entirely so, to infected seed potatoes and not directly to climatic conditions.

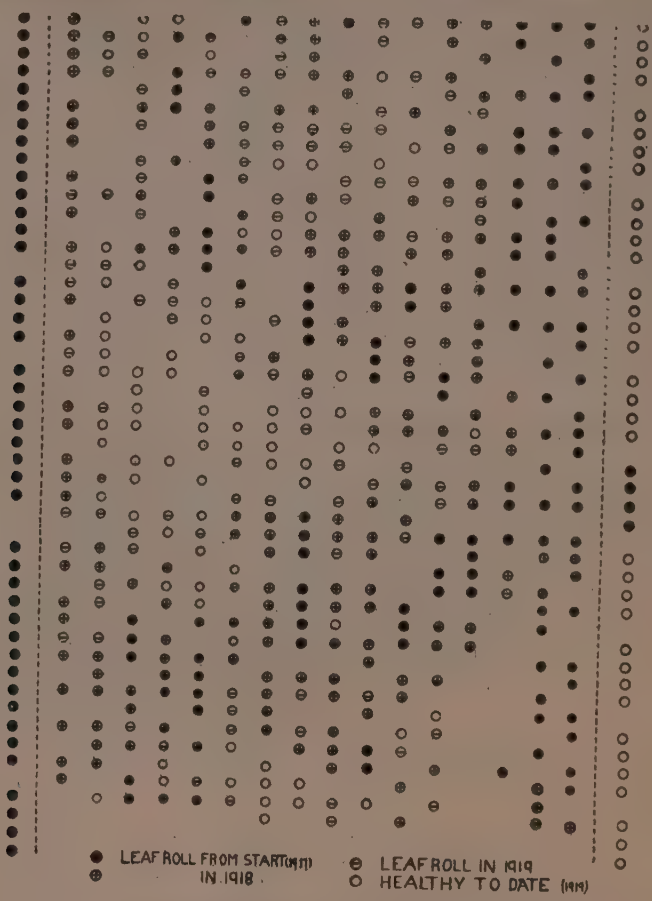

Fig. 15. The Charlottetown plot (as it stood for three years) of the experiment in which sister tubers were planted in Prince Edward Island, southern Ontario and Bermuda.

The circles inside the dotted lines represent plants, each of which was put back in its own place (but in a new plot) in 1917, 1918 and 1919. The plants outside the lines were present in 1917 only, as they belonged to another experiment. They are shown because they infected the outside rows particularly to the right. The spread of leaf roll from the original infection centres can be followed. The percentages of leaf roll were: 1917, 19 per cent; 1918, 60·7 per cent; 1919, 85·6 per cent.

It is interesting to follow these two lots of potatoes for another year. The Bermuda crop after being harvested about May, 1917, was placed in cold storage, it being then too late for the Canadian season of that year, but it was sent to Charlottetown and planted there in 1918 near the corresponding Charlottetown experiment. The latter was replanted in a new plot plant by plant in the same order in which it came

before (fig. 15). It was then found that 60.7 per cent of the Charlottetown plants were affected with leaf roll, while 97.5 per cent of the Bermuda plants were diseased. The percentage of leaf roll in the Charlottetown lot the previous year had been 19.0, and the Bermuda lot was practically the same, there being only four more leaf roll plants found there than in Prince Edward Island. The subsequent difference must have arisen from infection being more successful under Bermuda conditions, and it is here that the influence of climate is seen, as a secondary factor which predisposes to the disease.

These conclusions are borne out by a later experiment in which it was found that the infectiousness of the disease varied greatly in different parts of Canada. Uniform seed potatoes of the variety Empire State, both healthy and diseased, were planted in the nine localities listed in table 24 extending from Prince Edward Island to Saskatchewan. The plots were so arranged that there were two rows of leaf roll plants with one row of healthy plants between them, and five rows of healthy plants outside them on both sides, thus:—

H H H H H LR H LR H H H H H

Nothing developed in 1918, the year in which the experiment was begun. The affected potatoes produced typically leaf roll plants in all the experiments, and the disease did not appear in the healthy rows anywhere. Seed tubers were saved separately from each row and planted again in an experiment of the same plan in 1919. Leaf roll now appeared in varying amounts in the healthy rows, as shown in table 24, there being in general most in the centre row and progressively smaller amounts in the outer ones. The figures for the latter in the table are the average of the two corresponding rows.

TABLE 24.—Infection of healthy plants from neighbouring leaf roll plants in various parts of Canada. (Uniform Empire State potatoes throughout.)

Locality	Per cent leaf roll developing in healthy plants which had been grown in the previous year as follows:					
	Between two rows of leaf roll	Next row to leaf roll	Second row from leaf roll	Third row from leaf roll	Fourth row from leaf roll	Fifth row from leaf roll
Charlottetown, P.E.I.	15·0	21·2	2·5	2·5	0·0	0·0
Kentville, N.S.	35·0	12·5	6·5	1·2	2·5	1·2
Nappan, N.S.	20·0	16·2	0·0	0·0	0·0	0·0
Fredericton, N.B.	5·0	0·0	3·7	1·2	1·2	0·0
Lennoxville, P.Q.	17·5	17·5	0·0	0·0	0·0	3·7
Ottawa, Ont.	72·5	50·0	23·7	22·5	13·7	10·0
Thunder Bay, Ont.	0·0	0·0	0·0	0·0	0·0	0·0
Brandon, Man.	13·8	5·6	12·3	3·2	7·2	8·0
Indian Head, Sask.	5·3	1·4	1·4	0·0	0·0	0·0

The amounts for Brandon are probably not accurate owing to the crop being dried up when the notes were made. The same is probably true for Indian Head and Fredericton. It is probable that the disease did not spread at all at these three stations because samples from each row which were sent to Charlottetown developed no disease except one-half of one per cent in one row from Fredericton. The other data are believed to be accurate and comparable. Infection spread to a greater extent and further at Ottawa than anywhere else. Not only did it cross five rows but it seems to have become distributed irregularly all over the plots, contaminating several rows of other experiments, which were planted with healthy Green Mountain. This would indicate that leaf roll may be carried across at least five rows and possibly much further under certain conditions, a greater distance than has been noted elsewhere. in this country or in Europe. It is interesting that it appears to have extended more to one side than the other. This feature was also noted at Charlottetown and Kentville, but its significance is unknown. Kentville seems to be the next most favourable place for infection, and Charlottetown, Nappan, and Lennoxville follow in close order. The position of Fredericton, Brandon, and Indian Head is doubtful, but the indications are that the disease did not spread, while at Thunder Bay, in northern Ontario, no infection whatever took place. No reason has been found to account for this interesting fact. Climatically Thunder Bay is similar to the Maritime Provinces but the temperature is somewhat lower (cf. fig. 12). It should be noted that the variety Empire State is not particularly susceptible to leaf roll. On a scale on which the greatest known degree of susceptibility is represented by 90 its number would be about 14, this being a fair average for the commoner commercial varieties in Canada. It is possible that infection might have been secured at most or all places with a more susceptible variety.

There are indications that the extent of neighbour infection may vary not only from place to place but from season to season in the same locality. It has occurred regularly at Charlottetown for three successive years but with varying intensity. A preliminary experiment conducted with healthy Garnet Chili seed exposed to infection at Kentville in 1917 showed in 1918 that only 3 per cent of the plants became infected, yet up to 35 per cent of neighbour infection occurred in 1918-19 at the same station with a less susceptible variety. This result was well checked, because notes, which are essentially in agreement, were made by two competent observers and checked by a third.

The facts here presented furnish at least a partial explanation of the leaf roll situation in the Dominion. It is easy to see why the disease is present in those portions of southern Ontario of which Ottawa is typical. An inkling is also given of the way in which seed potatoes partly diseased with leaf roll might recover in northern

Ontario, the Prairie Provinces or in other places where no neighbour infection occurs, by the gradual suppression of the low-yielding leaf roll plants. The process might be particularly rapid if hill selection were practised. The comparative absence of the disease from the Maritime Provinces and Quebec as a whole, in most parts of which it is conveyed readily from one plant to another according to the experiments, is explainable only by the absence of infection; and its presence in isolated portions of these provinces is to be attributed to the introduction of diseased seed potatoes. Indeed there is good evidence of its being introduced and spread in Nova Scotia in this way. The growing of susceptible varieties is also a contributing factor, for Garnet Chili and Irish Cobbler are the predominating potatoes in the districts of

Fig. 16. Leaf roll in Empire State.

Nova Scotia and New Brunswick in which most leaf roll occurs. The absence of infection may not seem to be an adequate explanation of the facts, but five years' experience of the spreading-power of leaf roll once it is introduced into Prince Edward Island and Nova Scotia seems to leave no other alternative. This emphasizes the importance of seeing that no undue amounts of infected potatoes are imported into these provinces.

THE MODE OF INFECTION

Experiments point to the soil as the principal if not the only medium through which infection is carried, as Quanjer (55) stated. Six healthy Garnet Chili potatoes were cut into three sets each in 1918 and were planted as follows: One sister set alternating with leaf roll plants; another sister similarly alternating with tar-paper, which went down twenty inches into the subsoil; and the third sister set in an isolated spot. No sign of disease appeared in any plant during the first

year. The progeny of each individual was planted in units in 1919, with the result that the isolated plants proved to be all healthy; the plants which were not separated from leaf roll, all diseased; and the plants grown in the wooden cases, all healthy but one, the whole unit being affected in this case. It is not known how this last plant contracted the disease. Possibly the case in which it was grown did not project sufficiently above the ground to protect it fully. While the result, therefore, is not conclusive, it shows that most of the danger lies in the soil. This conclusion is confirmed by failure to convey the disease through the foliage by means of the Colorado beetle, both adults and larvæ of various ages, and the potato aphis. The plants in these experiments were grown in pots with sister-set checks, all covered with cheesecloth cages. Insects were collected which were found feeding on diseased and healthy foliage and were placed on different caged plants. No disease whatever developed during the first year nor in the progeny of any of the plants in the following year.

The agent which carries the infection in the soil is unknown. It seems to be out of the question that there can be a direct transfer from root to root, because the disease spreads too far—across three rows (7½ feet) at Charlottetown and at least 12½ feet at Ottawa. The agent is probably some soil-inhabiting animal, and its distribution may account for the spread of the disease in one place and its failure to spread in another. The relation noted by Quanjer between the nature of the soil and the infectiousness of leaf roll does not hold. Sandy soil was supposed to favour infection, and clay to restrict it. In the experiments recorded in table 24 the dispersal of leaf roll varied greatly without any relation to soil conditions. The nature of the soil used in each experiment is shown below, the places being listed in descending order of the infectiousness of the disease:—

Ottawa, Ont. (greatest spread)	Very heavy clay
Kentville, N.S.	Very sandy loam
Nappan, N.S.	Clay loam
Lennoxville, P.Q.	Clay loam
Charlottetown, P.E.I.	Clay loam
Brandon, Man.	Sandy loam
Indian Head, Sask.	Black prairie soil
Fredericton, N.B.	Loam
Thunder Bay, Ont. (least spread)	Sandy loam

SOIL INFECTION

It is possible that soil infection, that is, the persistence of the infective principle from one season to the next, may have been a factor in some of these experiments. Such an hypothesis would explain the isolated outbreaks of leaf roll in some of the plots at Ottawa, but it would not account for the progressive spread of the disease from centres of infection in the leaf roll experiments proper. All attempts made at Charlottetown, P.E.I., have failed to discover the presence of infection in the soil. In 1917, 100 healthy Garnet Chili potatoes were each numbered and cut into two sets. One hundred of the sets were planted in two rows on the spot where a leaf roll crop had been grown the previous year, and the corresponding sets were planted in soil which had raised a healthy crop in 1916. All the plants were healthy in the first year except one, No. 33 in both plots, the disease evidently coming with the seed. A small infection centre started round this plant, as appeared the following year. A row of plants presumed to have been healthy, but which were not entirely so, also adjoined the plot on clean ground and conveyed a further percentage of leaf roll to it.

All the plants were saved separately and their tubers were planted in order on clean ground in 1918, with results as shown in table 25. More disease developed in the plants originally grown on clean ground than in the other plot, and all the infection could be clearly traced to neighbouring diseased plants.

TABLE 25.—Result of planting potatoes some of which had been grown on presumably infected, and some on clean soil.

Variety	Grown on ground previously occupied by leaf roll plants		Grown on ground previously occupied by healthy plants	
	No. of plants	P.c. leaf roll	No. of plants	P.c. leaf roll
Garnet Chili	98	1·0	96	5·2

In another experiment in 1917-18 healthy tubers of the McIntyre variety were planted in a row which had produced all leaf roll plants in the previous year. No disease appeared in the plants in 1917, nor again in 1918 when the same potatoes were planted on clean ground. A similar result was obtained in 1918-19 when healthy Garnet potatoes were planted where a row of diseased plants had stood in 1917.

These conclusions are in agreement with the findings of Wortley (72) in Bermuda, but in disagreement with those of Quanjer (55). This author in a later paper (56) recedes somewhat from his original position, for he states that his later experiments in the south of Holland "have not led to uniform results," while in the north of that country he quotes Oortwijn Botjes (43) as having seen no traces of soil infection after making several experiments. Quanjer explains the fact that he found infection to persist in the soil in the 1915 experiment by a succession of mild winters, while the failure to duplicate this result in 1917 followed a very severe winter. It is suggested that the causal agent does not persist in a free state in the soil but is perpetuated by infected tubers which produce volunteer plants, if they are near the surface, or merely tuber-bearing stolons (which are photographed) if deeply buried. The possibility is also raised, on the strength of the work of Oortwijn Botjes above quoted, that the disease may spread from affected plants under certain circumstances much farther than had been supposed, or a distance of about 20 yards.

This ingenious theory of soil infection is likely to be questioned. It might explain the absence of infection under most conditions in Canada, but even here it is surprising how many volunteer plants come up. No particular attention has been paid to their appearance in relation to the weather, but we know that they may occur not infrequently for they have been a source of trouble in the experimental plots, and, in fact, an outbreak of mosaic in a healthy plot was traced to them in one case in 1918, when many were found after a winter of about normal severity. It is not known if potatoes which produce merely stolons and new tubers occur. Quanjer's hypothesis, however, entirely fails to account for Wortley's results in Bermuda, where no frost occurs and where two crops of potatoes are raised in the season, sometimes on the same piece of land. Were the soil capable of being infected, Bermuda would be saturated with the disease and it would be impossible to raise a healthy crop from locally-grown seed. This, Wortley states, is not so. At the same time it must be said that the two lots of Garnet Chili potatoes we got back in 1916 and 1918 after one season's growth in Bermuda had, respectively, 100 per cent and 97·5 per cent of leaf roll, but both samples were diseased to a considerable extent to begin with, and it is not known in what company they were planted in the south. Probably favourable conditions for neighbour-infection would account for both cases.

VARIETAL SUSCEPTIBILITY

An examination of potato fields throughout the country shows clearly that varieties differ greatly in their susceptibility to leaf roll. It is comparatively rare, for instance, to find more than a trace of the disease in varieties of the Green Mountain group [Stuart's (69) classification], even when they are grown side by side with a compara-

tively susceptible variety like Irish Cobbler, as happens so frequently in New Brunswick. Data from this source are not always comparable, and a beginning was made in 1918 to test a number of common varieties under uniform conditions. The method used was to plant a row of healthy potatoes alternating with a row of leaf roll potatoes. As far as possible the healthy plants were adjacent to diseased plants of the same variety on one side, but this could not be done in every case. There is ample evidence, however, that the disease is identical in all varieties although it does not present identical symptoms in all, and it is believed that no complication was introduced in this way. Susceptibility to leaf roll is measured by the percentage of the healthy plants which developed symptoms of disease in the following year. The crop from each plant was saved and planted separately. The amount of leaf roll which developed in each variety is shown in table 26.

TABLE 26.—Susceptibility to leaf roll as measured by the amount of disease developed when exposed to uniform infection.

Variety	No. of plants	Per cent leaf roll	
		1918	1919
Carman No. 1	22	0	9
Delaware	11	0	9
Green Mountain	21	0	10
Mill's Pride	21	0	10
Empire State	21	0	14
McIntyre	21	0	24
Early Six Weeks	11	0	27
Early Puritan	21	0	33
Irish Cobbler	22	0	36
Garnet Chili	20	0	50
Davies' Warrior	10	0	90

This experiment was done on a small scale and it is desirable that it should be repeated. Nevertheless the figures furnish evidence of dependability. The first four varieties, for example, which are practically synonymous and indistinguishable, show their relationship by reacting uniformly. The fifth, Empire State, is a close relative of the group but yet distinct, and it has a somewhat different co-efficient of susceptibility both in the experiment and in general experience. The early potatoes tested are somewhat more liable to the disease, which is also in accord with general observation. Garnet Chili is, of course, known to be quite susceptible, and Davies' Warrior, an English variety and probably a member of the "blue-sprout" group of which Rural New Yorker is the type-form, is most susceptible of all. The position of McIntyre is interesting. This potato forms about 70 per cent of the crop in Prince Edward Island and it is as nearly as possible free from leaf roll. A diseased plant has never been found in commercial fields so far as is known. Yet it is comparatively susceptible, and the reason for the absence of the disease must be the absence of infection. The potato is not grown outside of Prince Edward Island and eastern Nova Scotia. There is no interprovincial traffic in the seed and, therefore, no opportunity for the introduction of the disease from the more generally affected areas further inland. This bears out the contention that the general scarcity of leaf roll in the Maritime Provinces depends on the comparative absence of infection and not on climate or other causes.

PRACTICAL APPLICATIONS

Leaf roll, a full description of which is given, is a serious disease of the potato particularly in parts of southern Ontario. It is apparently caused by a specific agent, the nature of which is not known. The distribution of the disease is determined by the presence of the causal agent, favourable conditions for infection, the importation

of diseased seed potatoes, and the growing of susceptible varieties. Once a plant becomes attacked it does not recover, and its tubers always carry the infection. The effect on the plant is to reduce the yield considerably, frequently as much as three-quarters or two-thirds, but under certain conditions only one-half or one-quarter. There is no sign of the disease in the tubers at any time, or in the plants until one year after they become infected. The place in which a crop is grown has a considerable influence on the yield of leaf roll plants and on their power of disseminating the disease. The disease can spread from plant to plant, probably through the soil, over comparatively short distances in the field in most places, but in a number of other places in Eastern and Western Canada this may not occur at all or only to a slight extent. How uniform this may be found to be in other years is not known. The mechanism of the conveyance of leaf roll from plant to plant in the field has not been discovered.

Fig. 17. Leaf roll in Davies' Warrior.

Soil infection does not seem to occur. Varieties vary greatly in their susceptibility to the disease.

These findings have been applied to the practical control of leaf roll in a number of ways. The failure of two years of extensive selection trials in Nova Scotia has already been referred to and the cause of the failure detected. While leaf roll was being eliminated by the selection of tubers from large plants the disease was being conveyed to healthy and high-yielding potatoes, in which it produced no symptom until the following year. It is calculated that there are at least ten plants within the immediate sphere of influence of every leaf roll plant in the average field, any one of which is in danger of contracting infection. This being so, there is a moral certainty that if, in a place where the disease spreads, hill-selection is attempted in a crop containing even a small proportion of leaf roll plants, without any particular reference to the latter, some at least of the selections will be diseased. It is therefore necessary, if successful hill-selection is to be practised, to attend to a number of points:—

1. To determine if the disease spreads from plant to plant under local conditions. In the absence of a trial this may be assumed to take place, as it seems to do so in most places or in most years.

2. To make the selections from as healthy a crop as possible. It is a waste of time, besides being likely to be a failure, to attempt to build up a badly diseased stock when comparatively disease-free potatoes of most varieties can be secured.

3. To select plants as far removed from all leaf roll or otherwise diseased or weak plants as possible.

4. To grow the progeny of the selected plants as far removed as possible from other potatoes and to separate the units from each other for fear any should develop disease.

5. To remove at once (with their tubers) plants showing any sign of disease or weakness.

6. To spray the hand-selected plot thoroughly to reduce insect attacks. (This may have no relation to leaf roll but it is important from the standpoint of mosaic and possibly other diseases.)

With these precautions it should be possible to eliminate leaf roll and similar diseases. Careful work is required, as will be seen. There is ample evidence that selection conducted without reference to the points enumerated is not capable of getting rid of the disease. It is probable that the average man who is in need of good seed potatoes would be well advised to purchase them from a source of which he is sure. In the district of King's county, N.S., in which leaf roll was common, the disease was practically eliminated in a season by a large importation of healthy stock in 1916. These potatoes gave satisfaction for three seasons, but now (1919) the same trouble is recurring and the same measures are being taken to circumvent it. As long as the supply of healthy potatoes lasts this is much the quickest way, as well as being easy and cheap, for the new stocks cost little if any more than the old. In the ultimate resort, however, careful selectors living in favoured districts will have to be relied on for the nucleus of disease-free potatoes.

No seed potato grower in the best districts of the Maritime Provinces, Quebec, northern Ontario or elsewhere should be without a small seed plot for growing his hand-selected plants. This plot should be well isolated, if in the bush or some other unfrequented spot so much the better. The plot should be sprayed once a week throughout the season and carefully watched for diseased or weak plants. Among the advantages will be the fixing of the type, the elimination of mixtures and certain diseased and objectionable plants. and possibly the raising of the yield. Diseases like leaf roll and mosaic will also be held in check or eliminated if adequate precautions are taken.

Selection might in time have given the same result in Nova Scotia as a change of seed, but there are places which, according to present evidence, are practically forced to rely on the latter method. There are considerable areas of old Ontario of which this is true, leaf roll and similar diseases being so common as to contaminate the healthiest crops in a short time unless extreme isolation is resorted to. Cases are known in which imported stock is useless after one year. In other cases the gradual spread of leaf roll in a lot of potatoes, originally healthy, which had been imported season after season for a series of years has been noted with the following results: Potatoes 5 years in Ontario, 89 per cent leaf roll; 3 years, 63 per cent; 2 years, 24 per cent; one year, 15 per cent; same potatoes being grown for the first year in Ontario, 0 per cent leaf roll.

Growers who live under such conditions as these should make it a practice to obtain new seed potatoes periodically, depending on the rate at which deterioration sets in. When buying new stock nothing should be accepted but No. 1 grade seed potatoes, which have been inspected in the field and found to be true to name and practically free from unproductive plants.

MOSAIC

Although the mosaic disease of potatoes remained undescribed until nine years ago, the evidence points to its being of long standing, because, when attention was once drawn to it, the disease was found to be prevalent over large areas of North

America. It is surprising that it should have escaped attention for so long. Although the vigour of affected plants is not strikingly impaired as a general rule, or the yield reduced sufficiently to be obvious to the casual observer, the resulting loss is very considerable in the aggregate. The extent of the infestation in some of the best potato districts of Eastern Canada is referred to at some length in the course of the article. It has been calculated that five per cent of the total possible crop is lost in New Brunswick and Quebec from this cause, amounting to 1,525,000 bushels on the average. In certain years, such as 1918, the damage in Ontario has been calculated to be 2½ per cent of the crop, or practically 500,000 bushels.

SYMPTOMS

The symptoms of mosaic are simple and generally well marked. The leaves of affected plants are faintly mottled with light green or yellowish spots of varying size. In mild cases spotting of the foliage is the only sign of the disease, but as a general rule the leaves are also puckered to a greater or less extent, and this is often the first feature which catches the eye. The lighter colour in parts of the leaf is due to the reduction or suppression of the chloroplasts. The leaf-tissue is also comparatively

Fig. 18. Healthy (*left*) and mosaic (*right*) leaves of Green Mountain.

undeveloped, particularly the palisade parenchyma. The light-coloured areas are therefore abnormally thin and their growth is not as active or does not continue as long as is the case in the healthy regions. The result is that the leaf does not expand uniformly but is thrown into irregular puckers. In severe cases the leaves become distorted and considerably reduced in area. This feature, combined with the greater rigidity imparted by the corrugations, which makes the leaves assume more horizontal positions, exposes the lower part of the stem. The lower leaves also tend to disappear later in the season. The stalks of affected plants are somewhat weaker than normal and often fall to the ground as the season advances. The recumbent vines with few

lower leaves, present a characteristic appearance in September. It is sometimes noticed that mosaic plants do not bloom as abundantly as usual, and in fact in some cases the flowers are practically suppressed, the buds appearing but dropping before they open.

In very mild cases mosaic causes a hardly perceptible reduction in the size of the plant, but usually diseased plants are noticeably small. The yield is also affected. Depending on the locality and other conditions, the crop varies from about 60 per cent to more than 90 per cent of the normal. There is no visible sign of the disease in the tubers, or apparently in any other part of the plant except the leaves.

There are circumstances in which it is difficult or impossible to diagnose mosaic, even though it can be proved (as will be shown) that the disease is present. The spotting of the leaves may be entirely absent and the general appearance indistinguishable from that of healthy plants. The symptoms are said to appear sometimes in the early part of the season and to be absent later. The best time to make an examination would, therefore, be about nine to eleven weeks after planting. Even when the spotting does not entirely disappear it is sometimes very difficult to draw the line between normal and abnormal. This is most easily done in dull weather, or if the plants are placed in one's shadow while being looked at.

There is good evidence that potato mosaic belongs to the group of infectious-chlorosis diseases. There is a type of apparently non-infectious chlorosis of potato present in Canada (as well as in Germany, as noted by Orton (45), which is entirely

Fig. 19. Variegated leaf.

different from mosaic (fig. 19). The spots are bright yellow and larger and much more conspicuous than the true mosaic spots ever are. It has been found only in the variety Ashleaf Kidney. The appearance has been reproduced regularly for five years when tubers from variegated individuals were planted. It is, therefore, reproduced vegetatively, but attempts to transfer it to other plants have been a failure. A similar chlorosis has been noted recently by Quanjer (56) in Holland.

The symptoms of mosaic are not likely to be confused with those of any other disease. In certain cases slight frosts produce yellowish-white spots all over the exposed leaves. This has been noted particularly in northern Ontario, but once seen it will never be confused with the disease. Neither is it likely that insect punctures will cause trouble. Leaves infested with aphis are often puckered like mosaic leaves

but the contraction in growth is generally confined to one side, which gives them a lop-sided appearance, and there are no spots. The cause of the trouble can be found by turning the leaf over, when the aphides will usually be found, except late in the season. It is a question if the brown flecks of dead tissue which sometimes appear in late stages on some mosaic leaves are really connected with the disease. It may be that they are similar in nature to tip-burn, as mosaic plants are noticeably susceptible to this injury. At all events they are not sufficiently constant in appearance to form a diagnostic feature. The susceptibility of mosaic plants to late blight, as noticed by Quanjer (56), has not been observed.

GEOGRAPHICAL DISTRIBUTION

The disease was first discovered by Orton (45) in Germany in 1911 and it has since been recorded in a number of European countries. It was subsequently found in Maine, where it is present to a large extent on Green Mountain, Bliss Triumph and other susceptible varieties. The same is true for the greater part of the Maritime Provinces, Quebec, and Ontario. It is noticeable that the more highly developed potato-growing is in any district of these provinces, the greater is the amount of mosaic present. At the present time it seems to be practically impossible to secure Green Mountain seed potatoes free from infection in the best commercial districts of New Brunswick, and the situation in Maine is known to be generally similar, as indeed would be expected, for there is no natural barrier between Aroostook county, Me., and Carleton and Victoria counties, N.B. The only places where seed potatoes free from mosaic, or nearly so, of this variety have been found in Eastern Canada are Prince Edward Island and the counties of New Brunswick bordering on the gulf of St. Lawrence to the east and Quebec to the north. The average percentages of the disease recorded in these areas by the seed potato inspection service bring this point out clearly. These figures are as follows:—

Average per cent mosaic in Green Mountain,	Carleton and Victoria counties, N.B.	41·1
" " " " "	Madawaska county, N.B.	12·2
" " " " "	Eastern New Brunswick	11·2
" " " " "	Prince Edward Island	2·6

It is true that many more fields were inspected in the first district in particular than in the last, and therefore more poor ones were probably included, but it is significant that no fields free from mosaic were found anywhere but in Prince Edward Island and eastern New Brunswick, where many occur. The inference seems obvious. Mosaic is a comparatively recently introduced disease and has naturally spread most widely in places in which there is the greatest traffic in potatoes. So far as the Maritime Provinces are concerned it is working eastward and northward from Maine and New Brunswick.

The disease has been recorded in Manitoba, Saskatchewan, and Alberta, and it may possibly be present in British Columbia to an extent comparable to that found in the Maritime Provinces. On the prairies the disease is of little or no economic importance. The same situation seems to hold in the United States, where, according to the United States Plant Disease Survey, potato mosaic is recorded from twenty-six states. Severe outbreaks have been reported in one or more of the seasons 1917-18-19 in the following states: Alabama, Arkansas, Florida, Georgia, Louisiana, Maine, Massachusetts, Michigan, Minnesota, New Jersey, New York, and Vermont. During the same period slight attacks have occurred in Connecticut, Delaware, Idaho, Indiana, Iowa, Kansas, Maryland, Mississippi, New Hampshire, North Dakota, Ohio, Texas, Virgina, and Wisconsin. Apparently most disease is found in the eastern states from Maine to Louisiana, but bad attacks are not unknown as far west as Minnesota.

There is so much difference in varietal susceptibility that the reaction to the disease of the predominant varieties in any locality is a factor second in importance

only to climate in governing the distribution of mosaic. This is clearly seen in parts of the Maritime Provinces in which Green Mountain and Irish Cobbler are almost exclusively grown, being found side by side on many farms. The average percentage of mosaic recorded in 906 fields of the former variety in 1919 was 22·6 per cent, and in 640 fields of the latter 2·3 per cent, the greater part of which experience has shown to be due to Green Mountain plants accidentally present. No exact experiments on varietal susceptibility have been made but observation shows that the disease is found in greatest abundance on the following, among other, varieties: Green Mountain and probably all members of this group, including certainly Carman No. 1, Delaware, Gold Coin, Empire State, and Mill's Pride; Bliss Triumph; Early Rose; American Wonder. Varieties which seldom or never show mosaic are Rural New Yorker and probably other members of this group, including many English varieties with purple flowers, such as Up-to-date and Table Talk; Irish Cobbler; Garnet Chili. The variety which is predominant in any district would, therefore, obviously affect the amount of

Fig. 20. Mosaic plant (*left*) and healthy plant (*right*) of Early Rose.

disease present. In the Prairie Provinces, however, climate seems to be the all-important factor, for the disease is apparently absent or rare in even the most susceptible kinds. The same probably holds for the corresponding portion of the United States. Whether mosaic is really absent from these regions or is merely suppressed is a point which is further discussed later.

CAUSE OF MOSAIC

The cause of the disease is not known, although an extensive literature on the subject exists, for details of which the reader is referred to Clinton (18), Melchers (33), Allard (2), and Quanjer (56). This author, the latest worker on the subject, finds no anatomical peculiarity with the exception of the reduction in size of the palisade cells and the lighter colour of their chloroplasts. There is no necrosis of the phloëm, as was found in leaf roll, but he is inclined to think that infection is carried through this channel. The similarity of potato mosaic to the mosaic of tomato and tobacco is emphasized. The disease is readily transferred by grafting from tomato to tobacco and vice versa, the symptoms appearing in about two weeks; from tomato to certain varieties of potato (but not to others) and the reverse; and from Spanish

pepper (*Capsicum annuum*) to tomato and tobacco and *vice versa.* This corroborates the original and more extensive work of Clinton (16 and 18) and Allard (3), and proves that the similar diseases which affect many plants of the Solanaceae are not distinct, although some specialization comparable to that found in parasitism has occurred (Allard, 4).

As a result of Allard's work (3 and 5) on the mosaic of tobacco it may, therefore, be concluded by analogy that the causal agent of potato mosaic is present in the sap of diseased plants and is probably held by a fine filter but not by a coarse one. It is killed by some chemicals, such as alcohol and formalin, in certain strengths, but not in weaker concentrations; and by heating to almost 100° C. The peroxidase or other enzymes which survive some of these treatments are not the cause of the disease. The infective principle is precipitated by aluminium sulphate leaving a non-infectious super-natant liquid. Allard believes that the causal agent is an ultramicroscopic organism.

The recent work of Schultz and his co-workers (62) on potato mosaic has confirmed some of these findings, notably in developing a technique whereby successful inoculation can be made by means of the juice of diseased plants. It was found that bruising the leaves of the plant to be inoculated promoted successful infection. The relation of this feature to the presumed natural method of dissemination, by means of sucking insects, is not clear. It may have a direct bearing on the work of biting insects.

TRANSMISSION THROUGH THE TUBERS

As surmised by Orton (45) and first proved by Wortley (71), tubers from plants affected with mosaic transmit the disease. It has been found that this rule is not as invariable as in the case of leaf roll. A small but varying number of the tubers seem to escape infection, for the growth they give rise to is healthy in appearance. The percentage of apparently healthy plants produced in this way during the last three years is shown in table 27.

TABLE 27.—Percentage of apparently healthy plants produced by tubers from diseased plants

Year	No. of plants	P.c. of plants healthy
1917	356	2·8
1918	156	1·3
1919	41	7·1

Unfortunately the further behaviour of these plants was not followed up. It is hardly likely that they would have shown mosaic in the third year, because the incubation period of the disease under the conditions of the experiments is not a long one. The phenomenon may possibly be explained by assuming an unequal distribution of the infective principle in the mother plant. The same feature is sometimes found when plants first become infected with leaf roll, but it has never been noticed after the year in which infection takes place. According to Stewart (65), a similar difference may exist between two eyes of the same tuber. This has not been observed.

Apart from these exceptions the disease has been carried over a period of four years by planting tubers from mosaic plants. Under the conditions present at Charlottetown the diseased plants were no weaker in 1919 than they were at the beginning. The average yields of affected plants for the period 1916-19 were 16·2 ounces, 14·5 ounces, 15·0 ounces, and 18·4 ounces, and the percentages which these yields formed of those of healthy plants grown in an adjacent plot were 57·8 per cent, 69·7 per cent, 61·0 per cent, and 39·6 per cent. Similar results were being secured in more exact

experiments in which the behaviour of individual plants was followed from year to year until leaf roll was contracted from a neighbouring diseased row. All the evidence derived from experiments at Charlottetown, and from observation from all parts of Canada which have been visited, is opposed to Quanjer's (56) recent view that mosaic becomes progressively worse and finally degenerates into curly dwarf after two or more seasons. Nothing like this has been seen, and it may be said with some confidence that the phenomenon is not generally observed in Canada, and if anything like it occurs exceptionally, it is to be ascribed to infection with curly dwarf or some similar disease.

OTHER MEANS OF TRANSMISSION.

It was suspected since 1916 that diseased plants infect neighbouring healthy ones in the field. The observation was then made that a plot which had 20·8 per cent of mosaic on July 20 showed 28 per cent at the end of August. The inference from this observation was made clear in 1917. The diseased plants had all been carefully removed by hand at the end of the season in 1916, and the tubers from the healthy plants had been saved and planted by themselves. The crop which resulted was 33 per cent diseased, actually a higher figure than that found the previous year. Part of the same lot of potatoes, when used in twenty-eight experimental centres in Prince Edward Island, gave an average count of 26 per cent of mosaic in the same year. Another portion had the mosaic plants removed at the end of the season for three consecutive years, and the potatoes from the remaining healthy-looking plants grown in the following year in a row beside mosaic stock. Under this treatment the disease increased steadily, showing that infection from neighbouring potatoes exerts a stronger influence in disseminating mosaic then roguing carried out late in the season does in eliminating it. The figures for the three years of the trial were: 1917, 32·4 per cent mosaic; 1918, 67·8 per cent; and 1919, 77·0 per cent.

It seems that the transmission of mosaic from plant to plant may be effected in nature in a number of ways. While Clinton (18) was the first to inoculate a potato artificially (using juice from a tomato plant diseased with mosaic), and Güssow (22) transferred the disease to a healthy plant by grafting, Schultz, Folsom, Hildebrant, and Hawkins (62) were the first to prove that insects might be active agents of dispersal in the case of potato mosaic, following the similar work of Allard (1 and 5) with tobacco. It appears from this work that at least two species of aphides are carriers of potato mosaic. The activity of biting insects in this connection was not determined.

Quanjer (56) finds that the transmission of the disease is through the soil and only exceptionally through the air, but then in his critical experiments, at least, insects were probably excluded because the plants were grown in special glass cases.

While our experiments on insect transmission, which were performed on caged plants in the open, have given negative results, the disease spreads so widely and rapidly in some years that the theory of insect carriers seems to be the most reasonable explanation. This, of course, does not exclude transmission through the soil between neighbouring plants. In certain years mosaic has spread generally over healthy plots removed a considerable distance from any diseased plants both at Charlottetown, P.E.I., and Fort William, in northern Ontario. The incubation period may be so short under the conditions of these experiments that the symptoms of disease are sometimes strikingly visible in all the new growth in the top of the plant in the latter part of the season in which infection must have taken place. This happened in 1918, 1919, and probably in 1916. Thus in 1918, in three plots which were planted with previously inspected and proved healthy stocks of Green Mountain, Mill's Pride, and McIntyre, no mosaic developed in the first examination on July 29, but when inspected on August 27 mosaic was clearly discernible in the new growth of practically all the plants. The corrugated and spotted upper leaves and smooth lower ones presented a striking contrast (fig. 21). The transmission of mosaic from diseased to healthy plants of the variety Empire State was followed in 1919. The latter were healthy on July 24,

but symptoms of mosaic appeared in the upper leaves at the end of August. The disease spread with such rapidity in northern Ontario that Green Mountain seed potatoes, which were known to have been previously healthy and which were grown in complete isolation in 1918, being still healthy at that time, as a sample planted at Charlottetown in 1919 showed, had developed 48·1 per cent of mosaic by August 16, 1919, in which year they were placed in an adjacent plot to mosaic plants. The extent and rapidity of the dispersal of mosaic in this experiment were phenomenal. The disease had appeared by the middle of August not only in different parts of the small experimental plots but also in a considerable portion of the adjoining crop of Green Mountain potatoes which had been inspected in previous years and always found free from mosaic, as they still were in other portions of the field.

Fig. 21. Mosaic in upper leaves of Green Mountain, denoting recent infection.

The probability that the rapid dispersal of mosaic is to be attributed more to leaf-feeding insects than to soil agents is increased by the results shown in table 28. A row of mosaic plants was grown between two rows of healthy plants in 1918 and the plot was only sprayed sufficiently to prevent defoliation by insects. Tubers were saved separately from each row and planted in 1919, when the percentage of mosaic was determined. The same stock, healthy and diseased, was planted in another experiment in an adjoining plot in the same positions relative to each other. This plot was sprayed once a week with Bordeaux mixture to which a stomach poison, such as arsenate of lead or arsenate of lime, had been added, at all stations except the three western ones where no spraying was done. In this region there are, as a general rule, very few insects found on potatoes. In most cases a far greater amount of mosaic developed in the insect-infested plots than in those in which the potatoes were well sprayed. There was more than three times as much disease in the unsprayed plots as in the sprayed ones at Kentville, and nearly twice as much at Lennoxville and Nappan. At Charlottetown and Fredericton the difference was slightly in favour of the unsprayed potatoes. The figures for the western experiments are probably not reliable. These results strongly suggest that insects may be dangerous mosaic-carriers under certain conditions. It is unfortunate that circumstances made it impossible to attempt to correlate the transmission of the disease with the kind of insects present and their prevalence. The success of poisoned Bordeaux mixture in reducing infection would seem to point to the possibility of biting insects being active dispersal agents in certain places.

TABLE 28.—Relation of insect attack to the dispersal of mosaic.

Place of Experiment	Average percentage of mosaic developing in healthy plants beside diseased plants: Insects tolerated	Insects controlled (poisoned Bordeaux)
Charlottetown, P.E.I.	24·0	27·5
Kentville, N.S.	75·0	22·5
Nappan, N.S.	52·5	31·2
Fredericton, N.B.	6·2	10·0
Lennoxville, P.Q.	76·2	42·5
Ottawa, Ont.	–(1)	–(1)
Thunder Bay, Ont.	47·5	–(2)
Brandon, Man.	7·7	11·8
Indian Head, Sask.	10·2	2·6

(1) The symptoms of mosaic could not be diagnosed on any plant either in the diseased or healthy rows.
(2) Not determined.

INFLUENCE OF LOCALITY ON THE DISPERSAL OF MOSAIC.

The locality exerts a marked influence on the infectiousness of mosaic, on the yield of affected plants, and on their appearance. An experiment similar to the one recorded for leaf roll was conducted in 1918 at nine places in Canada, extending from the Atlantic to the prairies, with uniform healthy and mosaic potatoes of the variety Green Mountain, the planting being done in adjoining rows in the following order:—

H H H H H Mos. H Mos. H H H H H

The tubers were saved separately from each row and planted in an experiment of the same plan in 1919. While during the first season the plants grown from healthy potatoes were all healthy with the exception of 2·3 per cent slight mosaic at Ottawa, 1·1 per cent at Nappan and 0·4 per cent at Indian Head, there was hardly a row without some disease in the following year in most places (table 29). The figures for each pair of corresponding rows are averaged in the table.

TABLE 29.—Infection of healthy plants from neighbouring mosaic plants in various parts of Canada.

(Uniform Green Mountain potatoes throughout)

Locality	Percent mosaic developing in healthy plants which had been grown in the previous year as follows: Between two rows of mosaic	Next row to mosaic	Second row from mosaic	Third row from mosaic	Fourth row from mosaic	Fifth row from mosaic
Charlottetown, P.E.I.	45·0	27·5	15·0	17·5	22·5	6·2
Kentville, N.S.	32·5	22·5	13·7	12·5	10·0	1·2
Nappan, N.S.	55·0	31·2	18·7	32·5	20·0	18·7
Fredericton, N.B.	25·0	10·0	12·5	12·5	17·5	16·2
Lennoxville, P.Q.	57·5	42·5	0·0	2·5	5·0	5·0
Ottawa, Ont.	(1)	....	....	....	....	....
Thunder Bay, Ont.	80·0	(2)	(2)	(2)	(2)	(2)
Brandon, Man.	13·0	11·8	10·9	15·5	8·5	9·6
Indian Head, Sask.	4·5	2·6	2·2	0·0	0·0	1·8

(1) The symptoms of mosaic could not be diagnosed on any plants either in the healthy or diseased rows.
(2) Separate figures for each row were not taken but the average percentage of mosaic in the five rows was 12·5.

It is believed that these figures are for the most part reliable because they are supported in the main by the results obtained from samples from each row which were shipped to Charlottetown and grown there. For instance, it appears from both the original experiment and the sample that the outside rows at one side of the experiment at Fredericton and Nappan were infected from an exterior source. The samples also show slight infection in the first two rows only at Brandon and none at all at Indian Head, which is probably the correct result, as the inspection in the West was made under difficulties.

Combining all the information available the following conclusions seem justified: Mosaic spreads readily in most places as far west as lake Superior from a diseased plant to healthy plants in the first, second, third and fourth adjacent rows, and apparently farther than that in small quantities and irregularly. It appears from the fact that in some places infection is hardly transmitted, in others is practically limited to the next row, as at Lennoxville and probably also at Brandon, and in others goes much farther (e.g., Charlottetown, Kentville, and Nappan), that the dispersal depends on factors which vary from place to place. It may be suggested that agents in the soil and in the air carry infection [Quanjer (56) and Schultz *et al.* (62)], and that either of these, or both, or none of them may be operative. Mosaic is more infectious than leaf roll. It spreads farther and in some cases faster. The factors which control the transmission of the two diseases show some agreement (cf. tables 24 and 29), notably at Indian Head and Brandon, where both are least infectious, but there seem at first sight to be wide divergencies. This is seen especially at Thunder Bay, where no leaf roll was transmitted and where the infection from mosaic was at its height. It is practically certain, however, that some, at least, of the mosaic spread in this experiment within the season of 1919, while all the leaf roll infection must have been contracted in 1918. If so, the two diseases are not comparable, for all the evidence points to the fact that the season and all the varying factors it brings with it exert an important influence on the transmission of the disease from plant to plant in the field. Lastly the interesting conclusion is reached that a plant may have mosaic in a latent form and transmit the disease to other plants. This happened at Brandon, where in 1918 there was no appearance of the disease and little reduction in yield (3·9 per cent), yet the infection was conveyed to the next row, and the disease reappeared to the full extent when potatoes from the affected plants from this station were grown at Charlottetown in 1919. The symptoms were also largely suppressed at Indian Head in 1918, and little or no infection occurred there, but the disease reappeared in normal intensity in these potatoes at Charlottetown the following year. The question arises whether mosaic is really absent from certain susceptible varieties like Bliss Triumph when grown in the West, or whether it is merely suppressed. This may become an important question if western seed is used in districts in which mosaic assumes a severe form.

CONDITIONS WHICH BRING ABOUT THE SUPPRESSION OF MOSAIC.

The conditions which bring about the suppression of mosaic are not definitely known. Melhus (35) found that mosaic-diseased seed potatoes from Maine when grown in Iowa produced plants which, instead of mottling of the foliage, showed symptoms of curly dwarf and gave very low yields (0·237 to 0·32 pounds). No description is given of the appearance of plants from healthy tubers which were also grown, but judging from the yield (0·46 pounds), they were not very vigorous. It seems probable that the curly dwarf was contracted in the new environment and had no connection with mosaic. Degeneration of mosaic plants into curly dwarf has never been observed by us in the West; rather the reverse, for the plants become more vigorous.

Observation shows that a high temperature and favourable conditions for quick growth early in the season reduce the symptoms of mosaic. Thus in the Ottawa

experiments in 1919, and indeed throughout Ontario, it was practically impossible to recognize the disease even when healthy and diseased plants were grown side by side. June, 1919, was an extremely hot month, the mean temperature at Ottawa being 71·1° F., and growth was very rapid while the water supply lasted. In the previous year the disease was severe all over the province, particularly in early-planted potatoes. June of that year was a cold wet month. The mean temperature was only 61·8° F., and growth was very slow. Where potatoes were planted early they came up with

Fig. 22. Growth of mosaic (*above*) and healthy (*below*) Green Mountain at Charlottetown, P.E.I. The healthy seed yielded 22 per cent more than the diseased.

severe symptoms of mosaic, but when planted later the disease was much less noticeable. One case was observed in which part of the planting was done early and part late, the same potatoes being used throughout. The early potatoes had very severe mosaic, while in the others the disease would be classed as slight. It is interesting that the plants which came up during the cold weather with severe mosaic were practically killed by tip-burn during the hot weather of mid-July. The late-planted crop was much less affected.

An interesting corroboration of this observation was furnished by W. P. Fraser from Alberta in a private communication. A field which was all planted with the same stock was so badly frozen after the potatoes had come up that the foliage was

destroyed except on plants which grew on a slight knoll. The shoots grew up a second time, however, and at the time the field was inspected mosaic was found in severe form on the knoll but none could be seen in the rest of the field. The explanation is obviously the same as in the previous case. It was found in an attempt to duplicate this result artificially at Charlottetown that the local conditions were so favourable for the disease that it appeared whether planting was done early or late, and in the first shoots as well as in those which replaced them if the former were cut off. These results are of interest in connection with potato inspection for seed purposes. If suppression were to take place at times in the seed-growing districts it would be a serious matter, although it would not necessarily put a stop to the work, because certification is not based on a single report but on the accumulated inspections of years. As it happens, however, the difficulty is not known to occur in the best districts either in Eastern Canada or Northern Ontario.

It appears, therefore, that mosaic is more severe and more destructive in cooler regions than elsewhere. It adds to the danger of the disease that it is most at home in the best potato districts. Like the *Phytophthora,* it and the potato have probably been long associated although the disease may be comparatively new to North America.

INFLUENCE OF LOCALITY ON THE YIELD OF MOSAIC.

Data on the influence of locality and climate on the yield of mosaic plants were obtained in 1918 from the series of experiments already described. The results are shown in fig. 23. The general similarity in reaction of mosaic and leaf roll will be noticed by comparison with fig. 12. In both cases the three peak points for the total yield of diseased plants coincide, these being Brandon, Ottawa, and Kentville. The yield of mosaic plants relatively to healthy plants was highest at Brandon, Kentville, and Lennoxville, while the highest corresponding yields for leaf roll were found at Brandon, Ottawa, and Kentville. Ottawa would have been near the top of the mosaic list also were it not that the mosaic plants suffered severely from tip-burn and died early. This plot was sprayed once a week to control insects, and the treatment saved the healthy plants, so that they produced a magnificent crop, but it was not able to save the mosaic plants. Whatever the factors responsible for the differences in yield, they were evidently practically the same for both diseases. The reader is, therefore, referred to the discussion on the point under leaf roll.

The work was continued in 1919, but the spread of mosaic, extreme variations in the weather, and other conditions introduced such complications that it is difficult to interpret the results.

EFFECT OF ISOLATION ON THE CONTROL OF MOSAIC.

An experiment of the series being described consisted of isolating a plot of healthy Green Mountain potatoes as well as circumstances permitted to see if the crop would remain healthy in the absence of diseased plants. The work was carried out in 1918 and 1919. A small amount of mosaic developed at three stations in the first year: 4·3 per cent at Ottawa, 3·1 per cent at Indian Head, and 0·6 per cent at Brandon. It is difficult to account for this, because the seed was at that time, and still is, above suspicion. It is probable in the light of later results that the infection was contracted locally from diseased plants which were not removed a sufficient distance, the symptoms showing up the same year.

Naturally the degree of isolation varied, and with it the amount of mosaic which appeared in 1919. The percentages of disease recorded in that year are as follows: Fredericton and Lennoxville, 0·0 per cent; Kentville, 1·2 per cent; Charlottetown and Nappan, 2·5 per cent; Brandon and Indian Head, 3·4 per cent; and Thunder Bay, 48·1 per cent. The plot at the last place was not isolated in 1919 and the amount of disease recorded was contracted and appeared during that year. These results, although

not perfect, are very promising. They show that it is probable that the causal agent of mosaic is not present in the absence of diseased plants, but that traces of infection may spread considerable distances from the latter. The hope may be entertained that if careful spraying and early removal of mosaic plants are combined with thorough isolation, healthy stocks may be maintained of even the most susceptible varieties.

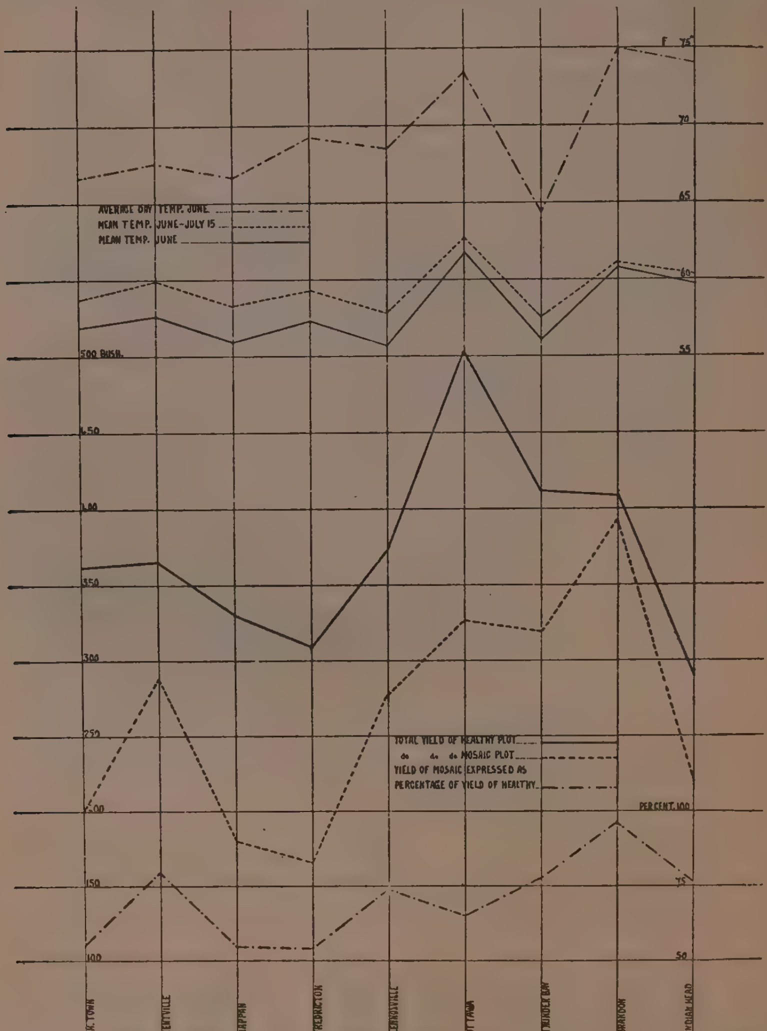

Fig. 23. Influence of locality and climate on the yield of mosaic and healthy plants (Uniform Green Mountain seed potatoes throughout.)

PRACTICAL CONSIDERATIONS.

Mosaic is a serious disease of some of the best commercial varieties of potatoes, notably the Green Mountain. The yield of affected plants is reduced by about one-third or one-quarter in the portions of Eastern Canada in which the trouble is most

prevalent. The disease is recognized by the faint yellowish-green spots present on the leaves. The cause is unknown, but it is probably something of a parasitic nature, for the disease is very infectious. Mosaic plants contaminate their neighbours growing in some cases as far as four or more rows away, in other cases not so far, and exceptionally hardly at all. The infection may possibly pass through the soil, but the principal agents of dispersal seem to be insects which feed on the leaves. Tubers from affected plants practically always carry the disease. The effect of mosaic is, therefore, permanent. Once a plant is attacked it does not usually recover, but the symptoms may be suppressed in the prairie provinces and southern Ontario for one season, and then reappear. The locality has a considerable influence on the yield of diseased plants and the degree of infectiousness. Cool weather and slow growth appear to favour the development of the disease. Isolation, insect control, and careful and early roguing are probably the best means of controlling the trouble.

The situation with regard to that very important variety, the Green Mountain, is such that unless active steps are taken it will soon be difficult or impossible to obtain mosaic-free seed potatoes in commercial quantities. This would be an important matter for all eastern potato growers, for the disease is an insidious one, causing a continuous reduction in yield which is generally overlooked. The danger is particularly serious for seed-potato growers. In this case the crop has to give satisfaction the following year also, and under conditions in which mosaic and similar diseases may be more virulent than in the north. Where the potato crop in a district is largely affected it is probable that nothing but community action on a fairly large scale will effect a lasting improvement. Mosaic is so infectious under most circumstances that piecemeal introduction of healthy potatoes cannot be expected to be more than a palliative. The course most likely to lead to success would be the discarding by a whole district of all diseased seed stocks and their replacement with healthy stocks, as far as that can be obtained, or with insusceptible varieties like Irish Cobbler and Rural New Yorker until the healthy potatoes have multiplied. The introduction of a small quantity of good seed potatoes into the same field as the poor, with a view to their replacing the latter the following year, is very likely to end in failure. An isolated seed plot should be kept by every potato grower for this purpose, because no matter how good the stock, disease is liable to creep in. The remarks made with reference to the control of leaf roll, by the use of a seed plot and the selection method, are all applicable to mosaic, and the reader is referred to them for fuller particulars.

CURLY DWARF AND RELATED DISEASES.

Very weak potato plants are to be found here and there over the greater part of the country which appear to be distinct from leaf roll, mosaic or any other well-defined disease. Such plants are rare in the Maritime Provinces, Quebec and the Prairie Provinces, but present indications are that they may be a factor of prime importance in some parts of southern Ontario. Degenerate stock in this area sometimes shows more resemblance to curly dwarf than to leaf roll or mosaic. Some attention has been paid to the matter during the last three years, and while much yet remains in doubt, it is clear that the forms of degeneracy about to be discussed are due to diseases which are regularly carried by the tubers, and which do not depend, once they are contracted, on climate or environment. The cause is probably not a simple one, that is, there appear to be at least two diseases involved. The relation of these to each other and to such previously-described troubles as curly dwarf, streak, bacterial ring disease and others has not been determined. For the present all that can be done is to describe the types which have been observed.

CURLY DWARF.

Typical specimens of the curly dwarf of Europe, "Kräuselkrankheit" of Appel (9,10) and other German authors, "curl" of Pethybridge (48,49), have not been

observed in America. It is possible that the same disease is present but that it has a different appearance on American varieties. Curly dwarf as originally understood is characterized by an extreme dwarfing of the plant, the foliage being wrinkled and clustered into a more or less compact upright mass resembling in appearance a head of curly kale. There are no normally outspread leaves. The dwarfing of the plant is accounted for by the fact that the stems, branches, leaves and leaflets all cease growth at an early stage. The leaf parenchyma continues to develop longer than the veins, with the result that the leaves are forced into deep corrugations, the margins become undulate, and the tips are generally curled downwards and inwards. The leaves, stalks and branches also become very brittle, breaking with a clean fracture if slightly bent. Accompanying this feature is a browning of the veins on the lower side of the leaves, and sometimes also of the vascular tissue within the leaf petioles and stems. Whether the browning is a constant characteristic or merely an occasional feature or a complication is not clear.

The colour of the foliage is a normal green or even a slightly darker green than usual. There are no yellowish spots as in mosaic, at least not until the plants are obviously dying. The plants do not bloom, and they mature at least one month or six weeks before the normal time. The yield is reduced to next to nothing, in many cases to nothing at all. Rarely does the crop weigh more than two ounces per plant, and frequently no tubers are produced, or such as develop are so extremely small that they die during the winter.

Fig. 24. Nearest approach to genuine curly dwarf (*right*) beside a healthy plant. Variety—Irish Cobbler.

Plants answering more or less to this description are found here and there throughout the potato fields (fig. 24). In the upright habit, size, corrugation and downward curling of the leaves, and yield, they approximate more to curly dwarf than to any other disease. They are not, however, nearly so compact in form, and, while provisionally classing them with the more marked European form of the disease, the question may be raised if they are not a separate entity. Doubts on this score are strengthened by the fact that some of the plants are larger than genuine curly dwarf specimens and have the curling and dwarfing confined to the upper leaves. In some cases of this sort the lower leaves drop off by degrees, and it is then reasonably certain from observation that we have to deal with a separate disease to which the name "leaf-drop" has been given. This form of disease and its possible

relationship is discussed more fully in a later paragraph. In other cases yet another apparently specific form of dwarfing has been distinguished which is now described under the name of "crinkle."

CRINKLE.

This type of degenerate plant which is common in some parts, at least, of southern Ontario, while approaching somewhat to the appearance of curly dwarf, has an even greater resemblance to mosaic. Yet all the evidence indicates that it is a distinct disease which has not been described before.

Affected plants are typically bushy, dwarfed specimens of about the same size and form as the low-headed type of leaf roll. The compact appearance of curly dwarf is absent. The colour is a pale green, but this feature is not marked. The most characteristic symptom is a pronounced and characteristic puckering and downward curving of the leaves. There is no distinct spotting as in mosaic, but diffused, slightly yellowish areas occur all over the foliage. As death approaches, this colour becomes more pronounced and is accompanied by rusty-brown spots, beginning near the tips of the leaves. The foliage is brittle and easily injured. There does not appear to be in normal crinkle any discoloration of the vascular tissue of the leaf or stem, such as occurs in streak (Orton, 46). The feature is present sometimes, but it is believed to be a complication. The plants usually live until the end of the season, behaving in this respect more like leaf roll or mosaic than curly dwarf.

Fig. 25. Leaf roll (1) and crinkle (2) in Irish Cobbler.

The lower leaves of plants which appear to be clearly affected with crinkle sometimes roll upwards in the same way as happens in leaf roll. It is not clear how constant this symptom is because the collection in which the disease was studied contained many diseases, often two or more of them in the same plant. It is probable that it is fairly constant. These leaves die gradually, beginning at the tips much as happens in leaf roll, and they may fall off. Although the description appears to resemble that of leaf roll, typical crinkle is easily distinguished from that or any other disease. This point will be made clear by reference to the figures (25, 26, 27). The question might be asked if crinkle is not a combination of leaf roll and mosaic. The evidence points to its not being so. Plants affected with both diseases simultaneously were present in the collection, and they showed the separate symptoms of each trouble clearly without any resemblance to the new disease. Crinkle and leaf roll can also exist side by side in the same plant.

The cause of crinkle is unknown. Observation shows it to be a serious pest in some parts of southern Ontario, notably near Ottawa, and the same or a similar disease has been noted in other parts of the same province. The peculiar appearance of affected plants was first noticed in 1917 in a collection of potatoes sent from Ottawa to Charlottetown. By 1919 it was possible to separate out apparently four diseases, leaf roll, mosaic, crinkle and leaf-drop, besides various combinations of these. Each type naturally differentiated itself gradually, so that the diagnosis in the earlier years was not as precise as in the later. It is not, therefore, possible to state definitely that tubers from plants of the crinkle type invariably reproduce the same appearance, but the general evidence is that they do, and that in crinkle we have to deal with a specific disease. It is also clear on general grounds that affected plants do not recover even under the favourable Charlottetown conditions. There has never been a case of recovery in strains which were diagnosed in 1917 and 1918 as belonging to the crinkle-leaf-drop group, which were then confused. These two diseases (as they are now

Fig. 26. Typical crinkle in an unknown variety.

believed to be) have persisted since that time in practically every case distinct from leaf roll, but on the other hand plants which then showed genuine leaf roll have since degenerated in a few cases into crinkle and leaf-drop. All these types were grown in adjacent rows. No exact experiments on neighbour-infection were made until 1919, definite results from which are not yet available. The plants which were being grown from healthy tubers interplanted with crinkle and leaf-drop did not look normal towards the end of the season. The variety used was Irish Cobbler, and the plants grew healthily until they neared maturity. On September 8, the foliage of individual stalks, or in some cases of the whole plant, was noticed to have turned a peculiar bronze colour. Red-brown, sunken streaks appeared in the branches and particularly in the leaf petioles. Following this the affected stalk or plant, as the case might be, died. A considerable portion of the same lot of potatoes was planted in an isolated plot in the same field without showing any such symptoms, but individual tuber checks were not provided. As the neighbouring diseased plants showed both crinkle and leaf-drop, it is a question which disease was carried to the Irish Cobbler, but the appearances strongly suggest that it was leaf-drop.

This experience, coupled with the development of crinkle and leaf-drop in plants which previously showed only leaf roll, raises the possibility that further work will prove the diseases to be infectious, as has been shown to hold for leaf-roll and mosaic.

It is doubtful if the European form of curly dwarf spreads to any extent, if at all; while on the other hand the serious deterioration of seed potatoes with which crinkle and leaf drop are sometimes associated would indicate them to be highly infectious. This feature may help to differentiate the various diseases.

Quanjer (56) (in a paper received after this section was written) presents evidence to show that mosaic and a form of curly dwarf ("Welvingsziekte") are different stages of the same disease. Plants of the variety Eigenheimer which showed very

Fig. 27. Leaf roll (1), a combination of leaf roll and mosaic (2), crinkle (3), and leaf-drop (4) in Green Mountain.

slight mosaic in 1916, when they were used in neighbour-infection experiments and were grown partly in glass cases and partly in the open field, developed into the above mentioned form of curly dwarf (Welvingsziekte) in 1917. According to this author it sometimes takes two seasons for the mosaic form to develop into the more severe type, but the transition from scarcely perceptible mosaic to the dwarf type may take place between one season and the next. Mosaic plants of the Zeeuwsche Blauwe

variety did not become dwarfed. The healthy plants (Eigenheimer) which contracted infection from the two former sorts showed normal mosaic the following year. Mosaic was also conveyed to Zeeuwsche Blauwe from both the mosaic and dwarf (Welvingsziekte) type of Bravo, Eigenheimer, Duke of York, and Splendo.

The figure and description of this dwarf form, particularly in the variety Bravo (56, fig. 23, pp. 9-10), leave little room for doubt that the latter and what we have called crinkle are identical. Quanjer is inclined to believe that this variety may have two separate diseases, although he connected a similar dwarf appearance in Eigenheimer and other varieties with mosaic by experimental methods. The possibility is mentioned that most or all of the plants showing the "Welvingsziekte" may also have mosaic, because the latter disease is said to be very widespread.

The identity of "Welvingsziekte" and crinkle is confirmed in a private communication from Quanjer, who recognized his disease in our photographs. There is, therefore, good ground for removing the disease from the curly dwarf complex, but it is at present impossible to say whether it is to be connected with another group or to be made independent. All the general evidence available in Canada is that it is not connected with mosaic. Crinkle, in association with leaf-drop, appears to be mainly responsible for the degeneration of potatoes in the neighbourhood of Ottawa. The running-out may be so rapid under these conditions that seed becomes almost worthless after one year. This has been going on since 1906. Before that time there are records of potatoes having been grown continuously in this locality for fifteen years without deterioration, the yield at the end of the period being higher than at the beginning (32). In 1906 there was a considerable introduction of European seed potatoes to this neighbourhood, and the probable cause of the running-out which then set in is to be traced to this event. The unfavourable season of that year can hardly be held responsible for a state of health of the crop which has persisted from that time to this, and remains unaltered even when the potatoes are removed to a more favourable climate. In this connection it is interesting to note that the disease appears to have a marked preference for certain varieties, some of which it now affects to the extent of 100 per cent, to the apparent exclusion of other diseases. The varieties thus involved are nearly all of European origin, among which may be mentioned Dalmeny Hero, Dalmeny Regent, Table Talk, Up-to-date, Davies' Warrior, Scottish Triumph, Superlative, and Extra Early Surprise.

There is nothing in this at all resembling the effects of mosaic. When that disease was first found in America in 1912 it was so abundant and widespread that it must have been present for many years before that time both in the United States and Canada. If, as is most likely, it were present before 1906, the question might be asked why did it not assume the extreme form in Canada sooner.

Mosaic does not develop into crinkle at Charlottetown but continues with mosaic symptoms unaltered for at least five years. In the parts of southern Ontario in which crinkle occurs mosaic was practically incapable of being diagnosed in 1919, there being no reduction in vigour and little in yield, yet the season had no such effect on crinkle. Finally it is almost certain that crinkle strains have persisted unchanged for three years at Charlottetown without any approach to the mosaic type. The question must be left without a definite answer for the present, but the Canadian evidence is that the two diseases are not connected.

LEAF-DROP

Another type of degenerate plant which has apparently not been described before, but has been classed with curly dwarf, must now be removed from that group. It is called leaf-drop because the lower leaves, beginning at the ground, drop off one by one, leaving a bare stalk with a little tuft of foliage at the top. (Figs. 27, 28, 29.)

This disease was first noticed at Charlottetown in 1915 in imported potatoes, and its history was followed for two years and then lost sight of. A more aggravated form of the disease was studied in 1917, 1918 and 1919, when it was connected with the earlier specimens with some certainty.

Fig. 28. Typical leaf-drop in an unknown variety.

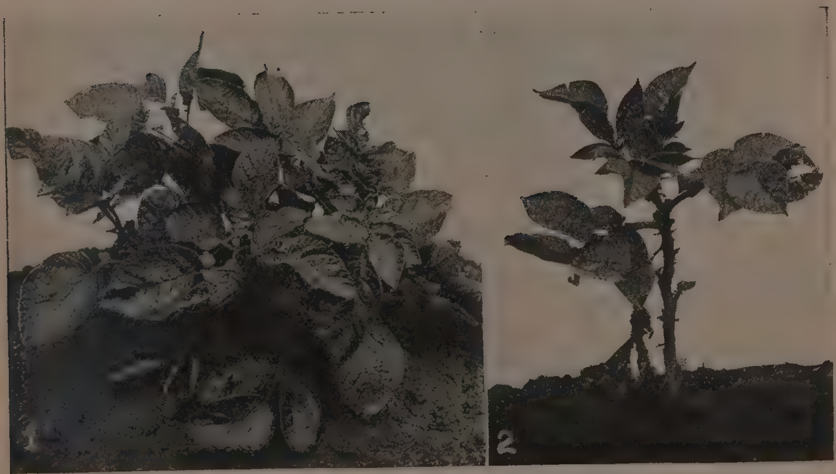

Fig. 29. Leaf roll (1) and leaf-drop (2) in The Scott.

Affected plants have an upright habit of growth, consisting in the majority of cases of a single shoot, possibly on account of weakness of the set. They may be as large as weak mosaic plants or as small as the most extreme curly dwarf. The stem is poorly covered with foliage. The leaves may be somewhat puckered and curved downwards at the tips, or they may be normally expanded. The area of the leaf is restricted but the lower ones are generally spread out more than the upper. The colour of the foliage is normal and there is no spotting. It is a constant characteristic of the disease, which separates it readily from all other types, that the leaves die and fall off one after another from the ground upwards, leaving in the middle or latter part of the season a small bare stalk surmounted by a cluster of yellow leaves. As the plant dies, which happens soon afterwards, the stem becomes limp and may fall over. The tissues of the stem and leaves are brittle. Streaks of a pronounced character are present in the leaf petioles and stems in some cases, but they are not so obvious in others.

There is a slight, sometimes an almost imperceptible, browning of the vascular ring of the tuber. No subsequent rot has been observed. Bacteria were observed in the discoloured regions of the stems and the tubers. These were found to be of several kinds, and an attempt to isolate a pathogenic organism failed.

The yield of diseased plants is extremely low, running from about one ounce per plant to nothing at all. It is certain from a study of the material worked with in 1915 and the following years that the disease is regularly transmitted by the tubers. The results with the second lot of material in 1917, 1918, and 1919 generally substantiate this view also. The probability that infection may be conveyed from plant to plant in the field has also been mentioned.

Leaf-drop takes second place to crinkle in the deterioration of potatoes in certain parts of southern Ontario, near Ottawa. It has been found most abundantly in three strains of Green Mountain and in two strains of Irish Cobbler, and to a smaller extent in other sorts. Other strains of these varieties from the same locality showed for the most part mosaic or leaf-roll, or a combination of these two diseases.

It is idle to speculate on the relationship of this disease until more work has been done. Attention may, however, be called to Appel's "Bakterien-Ringkrankheit" (7, 8, 9, 63) in connection with it. The description is short in all cases, but there is considerable similarity between the pathological features of both diseases, as the figures show. Judging from the remarks of Schander (60), the damage wrought by the German disease in the former provinces of Posen and West Prussia is similar to the effects of leaf-drop in parts of Canada. The description of this ring disease agrees in general with the symptoms of leaf-drop, except that the dark flecks on the leaves have not been observed, and there can hardly be said to be a copious development of bacteria in the vessels of the stem and tubers, although bacteria are present. Since a direct connection between the bacteria and the German disease does not seem to have been established this may not be a matter of importance. Even if bacteria do prove to be the causal agents, and the same disease is found to occur in Canada, it is to be hoped that a common name so inappropriate as bacterial ring disease will not creep into use.

The somewhat similar disease described by Spieckerman (63, 64) as being due to *Bacterium sepedonicum* appears to be of a different type. Other diseases which have a resemblance and possible relationship to leaf-drop are described by Smith in his work on "Bacteria in Relation to Plant Diseases", vol. 3, pages 166-167, and 207-219.

STREAK

Since the foregoing section was written Orton (46) has published a description of the disease which he discovered in 1912, and which has been generally known since under the name of Streak. This disease first became available for study in 1919, appearing in a form exactly agreeing with Orton's description. The outbreak was

first noticed in the second week of August on certain of the upper leaves of two well-developed and otherwise healthy plants of Green Mountain (fig. 30). The spots, at first, have a rather striking resemblance to the incipient stages of early blight (*Macrosporium Solani*), being small, dark brown or almost black, homogeneous and angular in outline. They do not extend very far, except where they come into contact with a vein, along which they spread in both directions, but particularly downwards. Once a main lateral vein, or the central vein of the leaflet, is reached, the progress of the disease is rapid. A pronounced brownish discoloration appears principally

Fig. 30. Green Mountain Plant attacked by the streak disease. Note the drooping leaves on the upper part of the plant.

on the upper side of the leaf veins, soon afterwards within the petiole, and finally in the stem (fig. 31). The streaks in external view are discontinuous, running the length of an internode and then disappearing. Once the petiole is invaded the leaf rapidly dies. Affected leaflets become brown and shrivelled, the original spots still showing up clearly, while the unaffected leaflets become pale green and then yellow (fig. 32). The dead leaf remains hanging on the plant (fig. 30).

Although only a few leaves became infected on both plants, the disease permeated the entire structure, including the stem, stolons and tubers, and probably the roots. The plants died prematurely. The stolons, and also the roots to some extent, became brown and shrivelled as compared with the corresponding portions of healthy plants. The vascular ring of the tubers also became slightly brown, but no rot set in. The

Fig. 32. Leaf showing later stage of streak.

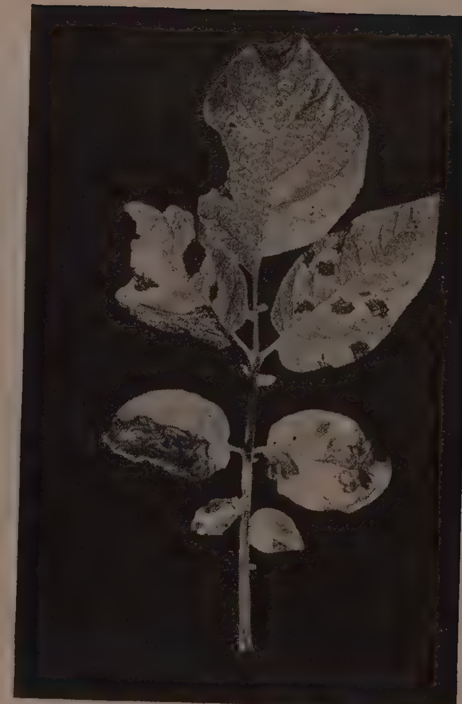

Fig. 31. Early stage of streak showing the spots on the leaflets and the discoloration in the leaf stalk.

necrosis of the petioles and stems in the region of the streaks was of a far-reaching nature. In the discoloured portion of the petiole a semicircle of disorganized tissue extended from one wing to the other in the parenchymatous tissue inside the vascular zone (fig. 34). A careful examination of the vascular bundles showed that the majority of both the external and internal phloëm groups were in process of disorganization. The cell walls became brown and contorted, and they finally collapsed. Apparently radiating in both directions from such groups, the necrosis invaded all the adjacent tissues in an irregular manner. All the elements of the xylem might be attacked with the exception of the vessels, and even the walls of these were sometimes turned brown. The cortex was most severely affected, and the collenchyma, and the epidermis to some extent, were also involved. In the material studied the two leaf traces in the wings of the petiole were most severely diseased. There was nothing left of their elements except the vessels, which were surrounded by an almost complete ring of disorganized cells (fig. 35). The disorganization extended from

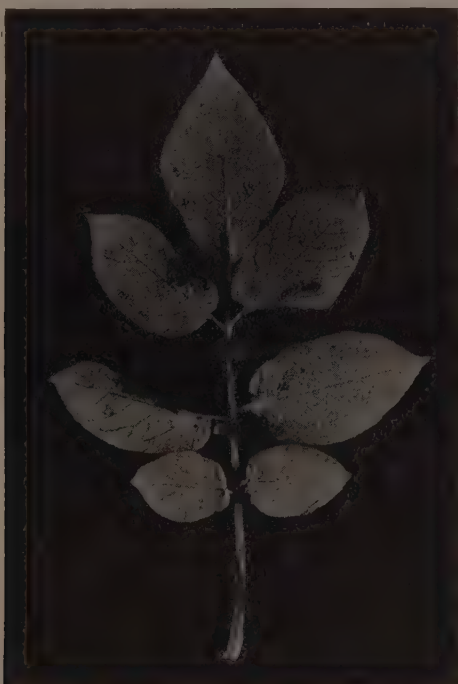

Fig. 33. Leaf stalk infected artificially with streak.

these through the zone of mechanically weak cortical tissue across the petiole to the corresponding vascular bundle of the other wing. The walls of the parenchymatous cells which became attacked turned a deep red-brown colour and swelled up. The cell then collapsed, practically obliterating the cavity, or the interior was found filled with granular *débris*.

Bacteria were present in the necrotic tissue, but the attempt to isolate a pathogenic organism failed. The disease, however, was proved to be infectious. Pieces of diseased petiole were inserted in a slit made in the petiole of a healthy leaf, the wound being then carefully bound up with tinfoil. Pieces of healthy petiole were similarly inserted in slits in other leaf stalks and similarly bound up. The affected tissue

conveyed the disease to the plants with which it came into contact. Browning and disorganization of the vascular tissue developed above, but principally below, the wound (fig. 33). No such development resulted in the plants into which healthy tissue was introduced.

In Orton's (46) original experience of streak, the disease was found spreading widely and rapidly over potato fields. No natural dispersal could be established with certainty in our plots.

Orton emphasizes the fact that the pathological picture of streak, attacking, as it does, well developed plants, is to be sharply distinguished from certain obscure "degeneration" diseases, in which, although streaks may be present, the plant is strongly dwarfed. This is absolutely necessary for the sake of clear thinking until a connection between such forms is established. The behaviour of the plants produced by the tubers of streak plants is not given by Orton, nor are we in a position to give it because the disease was not encountered until the last year of our work. Two facts may, however, be mentioned which raise a strong presumption that streak in a later stage may be connected with another disease.

The stock in which the streak, as already described, appeared was grown in as complete isolation as our experimental plots allowed in 1918 and 1919. It was entirely healthy, as far as our observations went, in 1918, but in 1919 it developed 2·5 per cent of mosaic. The appearance presented was otherwise quite healthy until streak was found in August, as described. It was then noticed that there were three very weak plants, which had been previously noted as misses, which just came above the surface of the ground about this time and died very soon afterwards. One of them was beside one of the large plants which developed streak, and another was near the second. No particular significance was attached to them at the time, nor, unfortunately, was any particular microscopical examination made, although they were described at the time as "small streak." The leaves, which were extremely small and scanty, were puckered and curved downwards somewhat like curly dwarf foliage, the petioles and stems were streaked with brown, and all the tissues were very brittle. Portion of the brown tissue of one of these plants was inserted into the petiole of a healthy plant similarly to the method followed in the case of streak, with the result that a brown necrosis developed in the vascular tissue around the wound. It was not as pronounced as that produced by the undoubted streak material, but it appeared to be not dissimilar.

The development of streak on the large plants which were near these dwarfs about the time that the latter came up, and the apparent similarity of the diseases on inoculation into healthy plants, raise the question if we have not here to deal with two phases of the same disease. If this should prove to be so, the dwarfs will probably be found to be the product of tubers of plants which showed streak (as described by Orton) the previous year, and such of them as succeed in breaking through the ground transmit the disease to neighbouring plants, probably, as the first stages of the disease show, through the agency of insects.

It may also be that the one or two diseases, as the case may be, here included have jointly or severally other relationships. In particular, the German bacterial ring disease must be mentioned.

Although Appel (*loc cit.*) emphasizes particularly the dwarf form of this disease he also mentions what we may call a primary stage in which the plant is of full size, but shows sometimes (but not always) towards the autumn black spots which have a partiality for the veins of the leaf.

Since the further course of this stage of the disease is not described it is impossible to identify it with Orton's streak. That there is some similarity is undoubted. The secondary stage, in which the plant, if it succeeds in coming up at all, is extremely dwarfed, shows an even greater similarity to the dwarf forms which we observed in close association with streak, and which we have some proof are a stage of the same

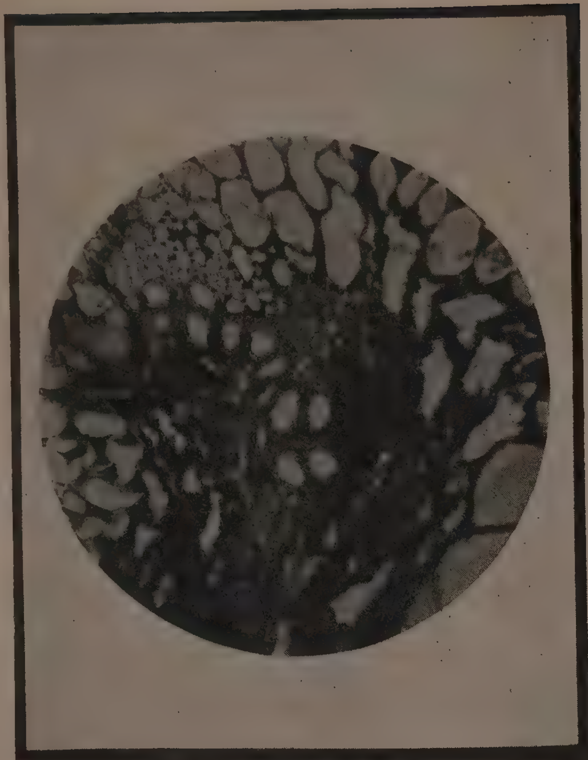

Fig. 35. Enlarged view of part of Fig. 34, showing necrosis of the xylem, phloem, cortex and collenchyma (x 228).

Fig. 34. Transverse section of leaf stalk attacked by streak (x 38).

disease. Similarity between the ring disease and leaf-drop has already been discussed. It must remain for future work to establish or disprove the connection between the various forms.

Whatever the nature of the diseases now being described may be found to be, it is evident that, even in its present restricted sense, the term curly dwarf (including the supposedly synonymous names used in other countries) embraces not a single disease, but a complex. It is suggested that the original name should be confined strictly to the type of plant all the leaves of which are clustered into a compact upright shape, as described and figured by Appel (9, 10) and quoted by Orton (45), and that the similar but recognisably different forms be known by the designations in the senses in which they are here used until such time as their real relationship be determined.

LITERATURE CITED.

For lists of further publications on potato diseases in general reference may be made to Appel (7); on late blight to Jones, Giddings and Lutman (No. 26), and to Pethybridge and Murphy (No. 53); on blackleg to Appel (No. 6), Pethybridge and Murphy (No. 52), and Morse (No. 40); on leaf roll to Appel and Schlumberger (No. 10), Orton (No. 45), and Quanjer (Nos. 55 and 56); on mosaic to Clinton (No. 18), Melchers (No. 33), Allard (No. 2), and Quanjer (No. 57); and on curly dwarf to Appel and Schlumberger (No. 10), and Orton (No. 45).

1. Allard, H. A. The mosaic disease of tobacco. Science II. 36: 875-876. 1912.
2. ——— A review of investigations of the mosaic disease of the tobacco, together with a bibliography of the more important contributions. Bull. Torrey Bot. Club. 41: 435-458. 1914.
3. ——— Some properties of the virus of the mosaic disease of tobacco. Jour. Agr. Research. 6: 649-674. pl. 1. 1916.
4. ——— A specific mosaic disease in *Nicotiana viscosum* distinct from the mosaic disease of tobacco. Jour. Agr. Research. 7: 481-486. pl. 2. 1916.
5. ——— Further studies of the mosaic disease of tobacco. Jour. Agr. Research 10: 615-631. pl. 1. 1917.
6. Appel, O. Untersuchungen über die Schwarzbeinigkeit und die durch Bakterien hervorgerufene Knollenfäule der Kartoffeln. Arb. Biol. Abt. Kaiserl. Gesundheitsamt. 3: 365-432. fig. 15. pl. 8. 1903.
7. ——— Die Bakterien-Ringkrankheit der Kartoffel. Kaiserl. Biol. Anstalt f. Land- und Forstwirtschaft. Flugblatt 36: 1-4. fig. 3. 1906.
8. ——— Beiträge zur Kenntnis der Kartoffelpflanze und ihrer Krankheiten. Arb. Kais. Biol. Anstalt f. Land- und Forstwirtschaft—I. 5: 377-435. 1907. 20 pages of references.
9. Appel, O. und W. Kreitz. Der derzeitige Stand unserer Kenntnisse von den Kartoffelkrankheiten und ihrer Bekämpfung. Mitt. Kais. Biol. Anstalt f. Land- und Forstwirtschaft. 5: 1-31. fig. 18. 1907.
10. Appel, O. and O. Schlumberger. Die Blattrollkrankheit und unsere Kartoffelernten. Arbeit d. Deut., Landw. Gesellsch. 190. 1-102. fig. 13. 1911. Literature cited.
11. Artschwager, E. F. Histological studies on potato leaf roll. Jour. Agr. Research. 15: 559-570. pl. C & 35-45. 1918.
12. de Bary, A. Die gegenwärtig herrschende Kartoffelkrankheit, ihre Ursache und ihre Verhütung. 75 pp. and plate. Leipzig, 1861.
13. Clinton, G. P. Report of the station Botanist. Report of the Connecticut Agr. Exp. Station. Part 4, 1903: 279-370. pl. 9-28. 1903.
14. ——— Report of the station Botanist; Downy mildew or blight, *Phytophthora infestans* (Mont.) de Bary, of potatoes. Report of the Connecticut Agr. Exp. station. Part 4, 1904: 363-384. pl. 32-37. 1905.
15. ——— Report of the station Botanist. III.—Downy mildew, or blight, *Phytophthora infestans* (Mont.) de By., of potatoes. Report of the Connecticut Agr. Exp. St. 1905: 304-330. pl. 23-25. 1906.
16. ——— Report of the Station Botanist. I.—Notes on Fungous Diseases. Report of the Connecticut Agr. Exp. Station. 1907-1908: 849-871. pl. 1. 1909.
17. ——— Report of the Station Botanist, 1909-10. II—Spraying Potatoes in Dry Seasons. Report of the Connecticut Agr. Station. Part 10. Biennial Rept. 1909-1910: 739-752. pl. 37. 1911.
18. ——— Report of the Station Botanist.—Chlorosis of plants with special reference to tobacco. Report of the Connecticut Agr. Exp. Station. 1914: 357-424. pl. 25-32. 1915. Literature cited.
19. Clinton, G. P., E. M. Stoddard and A. E. Moss. Report of the Station Botanist 1915. IV—Potato Spraying Experiments. 3rd Report of the Connecticut Agr. Exp. Station. Part 6. 1915: 470-487. 1916.
20. Coons, G. H. Michigan potato diseases. Michigan Agr. Exp. Station. Special Bull. 85: 1-49. fig. 41. 1918.

21. Coons, G. H. Seed tuber treatment potatoes. Phytopath. 8: 457-468. fig. 6. 1918.

22. Güssow, H. T. Mosaic disease transferred by inarching. Phytopath. 8: 494-495. fig. 1. 1918.

23. Harrison, F. C. A bacterial rot of the potato caused by *Bacillus solanisaprus*. Centralbl. f. Bakt. Abt. 2. 17: 34-39, 120-128, 166-174, 384-395, pl. 8. 1906.

24. Jensen, J. L. Moyens de combattre et de détruire le *Peronospora* de la pomme de terre. Mém. Soc. Nat. d'Agric. de France. 131: 1-130. 1887.

25. Jones, Dan H. Some bacterial diseases of vegetables found in Ontario. Ontario Agr. College (Guelph) Bull. 240: 1-24. pl. 10. 1916.

26. Jones, L. R., N. J. Giddings and B. F. Lutman. Investigations of the potato fungus *Phytophthora infestans*. U. S. Dept. of Agric. Bull. 245: 1-93. figs. 8. pl. 10. Bibliog. 1912. Also issued as Bull. 168 of the Vermont Agr. Exp. Station.

27. Jones, L. R. and W. J. Morse. Potato diseases and their remedies. III.—Relation of date of digging to development of rot. Fifteenth Ann. Rept. Vermont Agr. Exp. Station. 1901-1902: 219-223. 1902.

28. ——————— Potato diseases and their remedies. II.—Relation of date of digging to development of rot. Sixteenth Ann. Report Vermont Agr. Exp. Station. 1902-1903: 161-162. 1903.

29. ——————— Potato diseases and their remedies. II—Relation of date of digging to development of rot. Seventeenth Ann. Report Vermont Agr. Exp. Station. 1903-1904: 391-395. 1905.

30. ——————— Potato diseases and their remedies. Eighteenth Ann. Rept. Vermont Agr. Exp. Station. 1904-1905: 272-291. 1905.

31. MacMillan, H. G. Fusarium blight of potatoes under irrigation. Jour. Agr. Research 16: 279-303. pl. 37-41. 1919.

32. Macoun, W. T. The potato in Canada, its cultivation and varieties. Dominion of Canada Dept. of Agr. Bull. No. 90: 1-100. illustra. 1918.

33. Melchers, R. E. The mosaic disease of the tomato and related plants. Ohio Naturalist, 13: 149-173. pl. 2. 1913.

34. Melhus, I. E. Germination and Infection with the Fungus of the Late Blight of Potato (*Phytophthora infestans*). Agr. Exp. Stn. Univ. Wisconsin. Research Bull. 37: 1-64. fig. 8. 1915.

35. ——————— Notes on mosaic symptoms of Irish potatoes. (Abstract). Phytopath. 7: p. 71. 1917.

36. Melhus, I. E. and J. C. Gilman. An improved method of potato seed treatment. Iowa Agr. Exp. Station, Circ. 57: 1-8. fig. 9. 1919. Abs. in Phytopath, 8: p. 81. 1918.

37. Melhus, I. E. and L. I. Rhodes. A quick method of eliminating seedborne organisms of grain. Science. N. S. 50: p. 21. 1919.

38. Morse, W. J. Blackleg, a bacterial disease of the Irish potato. Maine Agr. Exp. Station, Bull. 174: 309-328. 1909.

39. ——————— Control of the Blackleg or black-stem disease of the potato. Maine Agr. Exp. Station. Bull. 194: 201-228. fig. 93. 1911.

40. ——————— Studies upon the blackleg disease of the potato, with special reference to the relationship of the causal organisms. Jour. Agr. Research 8: 79-126. 1917. Literature cited.

41. Murphy, Paul A. The mosaic disease of potatoes. Agr. Gaz. Canada. 4: 345-349. fig. 2. 1917.

42. Murphy, Paul A. and E. J. Wortley. Determination of the factors inducing leaf roll of potatoes particularly in northern climates. First progress report. Phytopath. 8: 150-154. fig. 1. 1918.

43. Oortwijn Botjes, J. Iets over het kweeken van ziektevrij pootgoed bij aardappelen. Directie van den Landbouw, 's Gravenhage. 1919.

44. ——————— Raising phloëm-necrosis and mosaic-free potatoes, and a source of infection whose nature has not yet been elucidated. Phytopath. 10: 48-49. 1920.

45. Orton, W. A. Potato wilt, leaf roll and related diseases. U. S. Department of Agriculture, Bull. 64: 1-48. pl. 16. 1914. Literature cited.

46. Orton, W. A. Streak disease of potato. Phytopath. 10: 97-100. fig. 1. pl. 1. 1920.

47. Osmun, A. V. (Report of Department of Botany). Twenty-ninth Ann. Rept. Massachusetts Agr. Exp. Station. 1916: 59a-64a. 1917.

48. Pethybridge, G. H. Investigations on potato diseases (Second report). Jour. Dept. Agr. and Tech. Instr. for Ireland. 11: 1-34. fig. 14. 1911.

49. ——————— Investigations on potato diseases. Journ. Dept. Agr. and Tech. Instr. for Ireland. 12: 1-28. fig. 5. 1912.

50. ——————— Investigations on potato diseases (Fourth report). Jour. Dept. Agr. and Tech. Instr. for Ireland. 13: 1-25. fig. 11. 1913.

51. ——————— Investigations on potato diseases (Fifth report). Jour. Dept. Agr. and Tech. Instr. for Ireland. 14: 1-24. fig. 3. 1914.

52. Pethybridge, G. H. and P. A. Murphy. A bacterial disease of the potato plant in Ireland. Proc. R. Irish Academy. 29, Sec. B: 1-37. pl. 3. Bibliography. 1911.

53. ——————————————— On pure cultures of *Phytophthora infestans* de Bary, and the development of Oospores. Scientific Proc. R. Dublin Society. 13: 566-588. pl. 2. 1913.

54. Quanjer, H. M. Die Nekrose des Phloems der Kartoffelpflanze, die Ursache der Blattrollkrankheit. Mededeel. van de Rijks Hoogere Land-, Tuin- en Boschbouwschool. 6: 41-80. pl. 2-9. 1913.

55. Quanjer, H. M., H. A. A. van der Lek en J. Oortwijn Botjes. Aard, verspreidingswijze en bestrijding van Phloeemnecrose (bladrol) en verwante ziekten, (Nature, mode of dissemination and control of Phloëmnecrosis (Leaf roll) and related diseases). Mededeel. van de Rijks Hoogere Land-, Tuin- en Boschbouwschool. 10: 1-90. pl. 12. 1916. (With long English summary).

56. Quanjer, H. M., J. C. Dorst, M. D. Dijt en A. W. v. d. Haar. De mozaiekziekte van de Solanaceeën, hare verwantschap met de phloeemnecrose en hare beteekenis voor de aardappelcultuur. (The mosaic disease of the Solanaceae its relation to phloëm-necrosis and its effect on potato culture.) Mededeel. van de Landbouwhoogeschool (Wageningen). 17: 1-70. pl. 1-8. 1919. (With English summary).

57. Quanjer, H. M. The mosaic disease of the Solanaceae, its relation to phloëmnecrosis, and its effect upon potato culture. Phytopath. 10: 35-47. fig. 14. 1920. (A longer English summary of No. 56 with some new figures).

58. Ramsey, Glen B. Studies on the viability of the potato blackleg organism. Phytopath. 9: 285-288. 1919.

59. Rosenbaum, J. and G. B. Ramsey. Influence of temperature and precipitation on the blackleg of potato. Jour. Agr. Research 13: 507-513. fig. 1. 1918.

60. Schander, R. Kartoffelkrankheiten. Fühling's Landw. Zeit. 58 Jahrg: 273-285. fig. 3. 1900 (?1910).

61. Schander, R. und M. v. Tiesenhausen. Kann man die Phloemnekrose als Ursache oder Symptom der Blattrollkrankheit der Kartoffel ansehen? Mitt d. Kais. Wilh. Inst. Bromberg. 6: 115-124. fig. 4. 1914. Abstract in Zeitschr. f. Pflanzenkrank. 25: 16-18. 1915.

62. Schultz, E. S., Donald Folsom, F. M. Hildebrant and L. A. Hawkins. Investigations on the mosaic disease of the Irish Potato. Jour. Agr. Res. 17: 247-273. pl. 8. 1919.

63. Spieckerman, A. Beiträge zur Kenntnis der Bakterienring- und Blattrollkrankheiten der Kartoffelpflanze. Jahresber. f. angew. Bot. achter Jahrg. (1910): 1-19 and 173-177. 1911. Discussion by Appel and others.

64. ——————————— Zur Kenntis der in Deutschland auftretenden Gefässkrankheiten der Kartoffelpflanze. Illustr. Landw. Zeit. 75: 1-8. fig. 10. 1913.

65. Stewart, F. C. Observations on some degenerate strains of potatoes. New York (Geneva) Agr. Exp. Station. Bull. 422: 319-357. pl. 12. 1916.

66. ——————— Missing hills in potato fields: their effect upon the yield. New York (Geneva) Agr. Exp. Station. Bull. 459: 45-69. 1919.

67. Stewart, F. C., G. T. French, S. M. McMurran and F. A. Sirrine. Potato spraying experiments in 1909. New York Agr. Exp. Station (Geneva). Bull. 323: 17-52. 1910.

68. Stuart, Wm. Disease resistance of potatoes. Vermont Agr. Exp. Station. Bull. 122. 1906.

69. ———— Group classification and varietal descriptions of some American potatoes. U. S. Dept. of Agr. Bull. 176: 1-56. pl. 19. 1915.

70. Westerdijk, Johanna. Das Spritzen der Kartoffeln in den Niederlanden. Jahresber. d. Verein f. angew. Bot. 16: Jahrg: 132-138. 1918.

71. Wortley, E. J. The transmission of potato mosaic through the tuber. Science, N. S. 42: 460-461. 1915.

72. ———— Potato leaf roll: its diagnosis and cause. Phytopath. 8: 507-529. fig. 16. 1918.